Broadcast and Multicast Communication Enablers for the Fifth-Generation of Wireless Systems

Deliverable D2.4

Analysis and Deployment of Terrestrial Broadcast in 5G-Xcast

Version v2.0

Date: 2019/07/22

Document properties:

Grant Number:	761498
Document Number:	D2.4
Document Title:	Analysis and Deployment of Terrestrial Broadcast in 5G-Xcast
Editor(s):	Christian Menzel, Jordi J. Gimenez, Clemens Kunert (IRT)
Authors:	Carlos Barjau Estevan, David Gomez-Barquero (UPV); David Navratil (NOK); David Vargas, Andrew Murphy, Simon Elliott (BBC); Tuan Tran (Expway); Christian Menzel, Jordi J. Gimenez, Clemens Kunert (IRT); Peter Sanders (one2many)
Reviewers	
Contractual Date of Delivery:	2019/05/31
Dissemination level:	PU[1]
Status:	Final – Updated Version for the Final Review
Version:	2.0
File Name:	5G-Xcast D2.4_v2.0

Disclaimer

This 5G-Xcast deliverable is not yet approved nor rejected, neither financially nor content-wise by the European Commission. The approval/rejection decision of work and resources will take place at the Final Review Meeting planned in October 2019, after the monitoring process involving experts has come to an end.

[1] CO = Confidential, only members of the consortium (including the Commission Services)

PU = Public

Abstract

Deliverable D2.4 provides a description of the analysis and technical solutions developed in the 5G-Xcast project for the delivery of Terrestrial Broadcast services (linear TV and radio) in 5G. It captures the relevant requirements and features for the transmission of linear TV and radio services under certain characteristics such as the possibility for receive-only mode involving user equipment without uplink. The document begins with an explanation of the most common requirements for Terrestrial Broadcast operation and their link to the 5G System. This is followed by an explanation of the configuration mechanisms and additional features developed in the 5G Core, NG-RAN and air-interface as a result of the work in the technical WPs of 5G-Xcast. Annex A includes a summary of the work conducted by some of the 5G-Xcast partners in 3GPP under the topic of this deliverable.

Keywords

5G, architecture, point-to-multipoint, Terrestrial Broadcast, ROM, SIM-free deployment, core network, access network, UE, BNO,

Executive Summary

Terrestrial Broadcast, as a 3GPP use case, was first addressed in LTE Advanced Pro 3GPP Release (Rel-) 14 in which the Multimedia Broadcast Multicast Service (MBMS) system was enhanced to operate in a dedicated mode for the delivery of linear broadcast services (i.e. radio and TV), fulfilling a wide set of requirements input by the broadcast industry [1].

5G-Xcast has evaluated a wide set of functionalities already present in eMBMS and newly introduced in Rel-14 (known as EnTV or FeMBMS). This information is contained in D3.1 “Performance of LTE Advanced Pro (Rel’14)” [2] and D4.1 “Mobile Core Network” [3]. From the analysis, a series of inefficiencies and limitations for the correct deployment of Terrestrial Broadcast were detected. Note that a study item for 3GPP Rel-16 [4] to which several 5G-Xcast partners have contributed has also evaluated some of these. However, many of the identified limitations have not been addressed.

The work conducted in 5G-Xcast goes one step further in order to address Terrestrial Broadcast service delivery from a different perspective and through a more efficient design of the Core Network, RAN procedures and air-interface in comparison to eMBMS (or LTE-based 5G Terrestrial Broadcast) and their corresponding MBSFN and SC-PTM bearers. This is done based on the most recent releases of 5G New Radio (NR) and 5G Core (5GC) specifications in order to leverage the new and more efficient radio layer and flexible system architecture.

The main design principles and design phases have been as follows:

- To minimise impact on the existing unicast procedures, to the extent possible;
- To enable the accommodation of Terrestrial Broadcast services in the 5G Core, RAN and air-interface architectures as an extension of the Multicast/Broadcast architecture developed in the project for other vertical use cases,
- To propose further enhancements to support Terrestrial Broadcast services according to different Mobile Network Operator (MNO) and Broadcast Network Operator (BNO) requirements (e.g. different network architectures, types of base stations – HPHT, MPMT, LPLT, coverage areas – MFN or SFN, etc).

The main objective of this approach is to benefit from the developments of a potential 5G Multicast/Broadcast mode suitable to be further configured to enable the delivery of Terrestrial Broadcast services. Therefore, User Equipment (UE) with a 5G-chipset capable of multicast/broadcast would be provided with Terrestrial Broadcast services with minimal additional standardization and manufacturing effort.

Table of Contents

Executive Summary 1
Table of Contents 2
List of Figures 3
List of Tables 4
List of Terms, Acronyms and Abbreviations 5
Glossary of Terms 7
1 Introduction 9
1.1 Means of Delivery for Terrestrial Broadcast services 9
1.2 Terrestrial Broadcast as a service 10
2 Technical requirements for Terrestrial Broadcast operation 11
2.1 Interaction with Content Service Provider: Ownership scenarios 11
2.1.1 Classical Scenario 11
2.1.2 Broadcast Network Operator scenario 12
2.2 User access to Terrestrial Broadcast services 13
2.2.1 Always-on transmission 13
2.2.2 Transmission independent of user location and density (ROM) 14
2.3 Terrestrial Broadcast distribution area configuration 14
2.3.1 Control of distribution area parameters 14
2.3.2 Shape of distribution areas 14
2.4 Service Identification and Service Continuity 15
3 5G System Configuration and Mechanisms for Terrestrial Broadcast Service Provision 16
3.1 Basic steps to configure Terrestrial Broadcast from CSP to Core Network 16
3.2 Simplified 5G-System architecture for Terrestrial Broadcast: NFV and Network Slicing 18
3.3 The roles of NFV and Network Slicing 19
3.4 RAN Architecture and Procedures 20
3.5 Physical Layer Signaling and Service Discovery without uplink involvement 21
3.6 Air-Interface Design 23
4 Conclusions 25
A Current Approach to Terrestrial Broadcast in 3GPP 26
A.1 EnTV/FeMBMS (LTE-based 5G Terrestrial Broadcast) Standardization Activities within 5G-Xcast 26

List of Figures

Figure 1: Classical scenario 12
Figure 2: Broadcast Network Operator (BNO) scenario 12
Figure 3: Modification of the classical scenario - Access and Core Network of a CSP is used by an external CSP. 13
Figure 4: BNO scenario - The infrastructure of the BNO is used by multiple CSPs. 13
Figure 5: Example of a cell-layout and frequency deployment 15
Figure 6 Network resource allocation for Terrestrial Broadcast 18
Figure 7: Reduced 5G System Architecture for Terrestrial Broadcast 19
Figure 8: 5G network slices including a network slice for Terrestrial Broadcast........... 20
Figure 9: Three deployments consisting of a nation-wide SFN, a regional SFN and a single cell transmitter and their relation to Terrestrial Broadcast Service Areas. 21
Figure 10: Example of a USD-list 23
Figure 11: Example of SC-PTM mapping in LTE... 23

List of Tables

Table 1: Glossary of terms 7
Table 2: Potential 5G-NR numerologies for Terrestrial Broadcast 24

List of Terms, Acronyms and Abbreviations

5G-NR	5G New Radio
5GC	5G Core
5GS	5G System
AMF	Access Mobility Management Function
AN	Access Network
BCCH	Broadcast Control Channel
BWP	Bandwidth Part
CCCH	Common Control Channel
DCCH	Dedicated Control Channel
BNO	Broadcast Network Operator
CAS	Cell Acquisition Sub-frame
CN	Core Network
CP	Cyclic Prefix
CSP	Content Service Provider
DCI	Downlink Control Information
DL-SCH	Downlink Shared Channel
DTCH	Dedicated Traffic Channel
EARFCN	E-UTRA Absolute Radio Frequency Channel Number
gNB	5G Node B
G-RNTI	Group Radio Network Temporary Identifier
HPHT	High Power High Tower
ID	Identifier
LPLT	Low Power High Tower
MBMS	Multimedia Broadcast Multicast Service
MBSFN	MBMS over Single Frequency Networks
MCC	Mobile Country Code
MCH	Multicast Channel
MCCH	Multicast Control Channel
MCS	Modulation and Coding Scheme
MIC	Message Integrity Check
MFN	Multi Frequency Network
MNC	Mobile Network Code
MNO	Mobile Network Operator
MPMT	Medium Power High Tower
MTCH	Multicast Traffic Channel
NEF	Network Exposure Function
NFV	Network Function Virtualisation
NRF	Network Repository Function
PBCH	Physical Broadcast Channel
PDCCH	Physical Downlink Control Channel
PDSCH	Physical Downlink Shared Channel
PCFICH	Physical Control Format Indicator Channel
PSS	Primary Synchronization Signal
SSS	Secondary Synchronization Signal
QoS	Quality of Service
RAN	Radio Access Network
RNTI	Radio Network Temporary Identifier
ROM	Receive Only Mode
SACH	Service Announcement Channel
SC-MCCH	Single Cell Multicast Control Channel
SC-MTCH	Single Cell Multicast Traffic Channel
SC-PTM	Single Cell Point To Multipoint
SFN	Single Frequency Network
SIB	System Information Block
SIM	Subscriber Identification Module
SLA	Service Level Agreement
SMF	Session Management Function

TMGI	Temporary Mobile Group Identity
TX-Pwr	Transmit Power
UE	User Equipment
UPF	User Plane Function
USD	User Service Description
xMB	Reference point / Interface
XCF	Xcast Control Plane Function
XUF	Xcast User Plane Function

Glossary of Terms

The glossary below reproduces those terms from D2.1 that are relevant in the context of Terrestrial Broadcast.

Table 1: Glossary of terms

Term	Definition
Broadcast	The usage of the term “broadcast” within the mobile industry originates from mobile systems that are always operated in spectrum allocated to mobile services, i.e. that have both uplink and downlink, and the UE is registered / attached with the network. This type of “broadcast” – together with “multicast” (see definition below) – has first been specified by 3GPP in Rel. 6 within MBMS. eMBMS for LTE was introduced in 3GPP Rel. 9 and supported only this type of “broadcast”, which is a point-to-multipoint content delivery method for UE that is required by the specification to register/attach to the network for the “unicast” operation. That means, the UE is always capable of “unicast” communication with the network, although UE’s “unicast” communication capability may not be required for the point-to-multipoint content delivery method in cases when the associated procedures (for e.g. the file repair or the reception reporting) are not used. In this case of “broadcast” the UEs do not need to join the delivery session as with “multicast”. In short, the UE is required to integrate uplink capabilities before being able to receive broadcast content.
Hybrid multimedia service	Consists of both linear and on-demand elements. They complement each other in the sense of enriching the linear offering but also in order to inter-relate both types of services. This requires a certain level of integration when producing the content. Examples include slideshows for digital radio or second screen television.
Linear audio-visual service	Refers to the “traditional” way of offering radio or TV services. Listeners and viewers “tune in” to the content organized as a scheduled sequence that may consist of e.g. news, shows, drama or movies on TV or various types of audio content on radio. These sequences of programmes are set up by content providers and cannot be changed by a listener or a viewer. Linear services are not confined to a particular distribution technology. For example, a live stream on the Internet is to be considered as a linear service as well.
Multicast	The term “multicast” – together with “broadcast” – has first been specified by 3GPP in Rel. 6 within MBMS. eMBMS for LTE was introduced in 3GPP Rel. 9 and is a point-to-multipoint content delivery method for UE that are required by the specification to register/attach to the network for the “unicast” operation. In comparison to “broadcast” (see above), “multicast” always comprises – in addition to the point-to-multipoint content delivery – a “unicast” connection in the uplink direction that is required for associated procedures (e.g. for file repair or reception reporting, switching between unicast, multicast and broadcast). In the case of “multicast” the UEs always join the delivery session.
Multimedia service	A service that handles several types of media (such as audio and video) in a synchronised way from the user's point of view. It may involve several parties and connections (different parties may provide different media components) which both can be added and deleted within a single communication session. Multimedia services are typically classified as interactive (i.e., conversational, messaging, retrieval) or distribution (i.e., with/without user control) services.

Term	Definition
Multipoint	A service attribute denoting that the communication involves more than two network terminations
On-demand audio-visual service	A communication service providing any type of audio-visual content, which gives users the freedom to choose when to consume the content. The user can select individual pieces of content and can control the timing and sequence of the consumption. Examples of popular on-demand services are TV catch up and time-shifting. Other forms of on-demand services include downloading content to local storage for future consumption or access to audio-visual content for immediate consumption.
Point-to-multipoint (PTM)	A service attribute denoting that data is concurrently sent to all users (broadcast) or a pre-determined subset of all users (multicast) within a geographical area.
Point-to-point (PTP)	A service attribute denoting that data is sent from a single network termination to another network termination.
Receive-only-mode (ROM) Broadcast or “Terrestrial Broadcast”	For historical reasons what broadcasters understand by “broadcast” are systems that possess only a downlink to distribute their content in a Point-to-Area mode (e.g. as for DAB+ or DVB-T2). Usually these systems are operated in spectrum bands allocated to “broadcast service” and that do not provide an uplink. In 3GPP, this type of broadcast was first introduced with 3GPP Rel. 14 and it is called “Receive-Only-Mode (ROM) broadcast”. The system is also known as FeMBMS or “LTE-based 5G Terrestrial Broadcast” For “ROM broadcast”, the UE need not register/attach with the network. Prior to 3GPP Rel. 14, “ROM-broadcast” was not supported by 3GPP.

In the context of Terrestrial Broadcast in the present deliverable, some specific terms are used:

Term	Definition
Broadcast company	A broadcast company is a company that owns one or more broadcast services. Examples for broadcast companies are ZDF or Bayerischer Rundfunk in Germany or BBC in the UK.
Broadcast service	Broadcast service means a specific programme of a broadcast company. Examples for broadcast services are ZDFinfo or ZDFneo (of the broadcast company ZDF) or BBC One of broadcast company BBC. In a technical sense a broadcast service consists of the continuously transmitted data stream of content (e.g. audio content, audiovisual content or even data content) that is transmitted via specific radio resources and comes from a play-out center.

1 Introduction

5G-Xcast examines how Multicast and Broadcast can be added into the 5G System as an extension with minor modifications to the existing 5G System (5GS) designed primarily for unicast as defined in 3GPP from Release 15 comprising both, the RAN (5G-NR and NG-RAN) and Core (5GC).

Within the multiple applications of 5G technology to media and entertainment use cases, 5G-Xcast has defined a holistic approach for media distribution (focused on audiovisual services) to large audiences. One particular set of services is linear TV and radio transmitted over the air, termed here as “Terrestrial Broadcast” services. These services consists of a pre-scheduled series of audiovisual content, including live and pre-recorded content such as news, magazines, entertainment, music, sport, cinema, documentaries, among others. Due to their nature, the transmission is “always-on” and not triggered or modified by users. Note that it is possible to combine Terrestrial Broadcast services with additional content (e.g. Hybrid models) which imply the reception of the Terrestrial Broadcast service together with a unicast connection.

1.1 Means of Delivery for Terrestrial Broadcast services

Linear TV and radio services can be delivered with multiple options using 5G technology.

- OTT live streaming via unicast. This option implies that the linear TV/radio traffic is delivered via a unicast connection between the UE and a streaming server. This is the model generally extended in LTE smartphones where users can access the live video streams of the TV and radio offer via a website or an app. In this case unicast 5G plays a role and further consideration may be given to new features of 5G such as network slicing in order to fulfill certain operator, network and QoS requirements.
  This delivery option is implicitely supported by the 5G-Xcast solution as unicast delivery of media traffic is part of the complete architecture.

- OTT live streaming via unicast/multicast/broadcast. This option implies that a linear TV/radio service is accessible via unicast and that the network may use multicast/broadcast functionalities as network optimization options to deliver the traffic in the most efficient way according to factors such as network congestion or demand.
  This delivery option is a core option in the 5G-Xcast solution which permits the dynamic switching between unicast, multicast and broadcast delivery modes as a network optimization feature. Information about the design and architecture proposed can be found in D3.2, D3.3, D3.4, D4.2, and D4.3.

- Terrestrial Broadcast (TV/Radio) as a Service. This approach inherits traditional concepts developed for eMBMS and the EnTV Study Item where there is a specific service layer and mechanisms to determine the way the service is going to be provided in terms of broadcasters’ requirements such as intended QoS, data rate, coverage, etc.
  This feature is covered by 5G-Xcast in D3.2, D3.3 and D4.3. The approach is however based on 5GS (and not LTE) with added features that are not part of current 3GPP standards but have been developed within the project. In this respect, 5G-Xcast considered that, instead of reusing the existing EPS eMBMS architecture for Terrestrial Broadcast in 5GS, a simpler architecture developed as a configuration option of the generic 5G-Xcast architecture could provide benefits considering some of the pre-existing functional properties of 5GS such as network slicing or NFV.

1.2 Terrestrial Broadcast as a service

In the scope of this document, “Terrestrial Broadcast as a service” is considered and is characterized by the following:

- that the 5G system must support, in addition to regular UEs, those that do not possess an uplink capability in any access network (ROM);
- that the lack of uplink implies that the UEs remain completely unknown to the 5GS (there no procedures for attachment and/or registration);
- that it could be operated in spectrum with only a broadcast allocation (although operation in spectrum with a mobile allocation is not excluded); and,
- that it is used for linear content reception (i.e. television and radio services).

Terrestrial broadcast permits the simultaneous transmission of multimedia content to an unlimited number of receiving UEs thanks to a user-agnostic resource allocation and the fact that its radio range is not restricted by an uplink i.e. by the limited transmission power of the UEs. Thereby Terrestrial Broadcast permits a highly effective spectrum usage where, if identical content is to be delivered to a large amount of receiving UEs per cell. Furthermore, Terrestrial Broadcast permits operation in synchronized Single Frequency Networks (SFN), that might additionally increase efficiency of spectrum usage and avoid inter-cell interference in the case of frequency reuse-one deployments.

The specific characteristics and deployment scenarios of Terrestrial Broadcast are described in more detail in the present document. From a technical viewpoint the main issue is how the data streams of specific broadcast services of broadcast companies are transported from the play-out centre (CSP) via the 5GC (broadcaster terminology: “5G-based distribution network”) and via the 5G-RAN (broadcaster terminology: “5G-broadcast transmitters”) and how they can be received by ROM and SIM-free UEs and UEs that are not attached to a particular transmitter (TX-free).

The 5G System can also be configured and used as a Terrestrial Broadcast system. The call flow as described in D4.3 [5] Fig. 3 is capable of providing the network setup for transmitting Terrestrial Broadcast services. Terrestrial broadcast also requires only a subset of the 5G core network functionalities. At radio access level, RAN multicast areas can be configured as Terrestrial Broadcast service areas. The radio interface of 5G as described in D3.2 [6] can be used for Terrestrial Broadcast by supporting broadcast networks consisting of large (HPHT), medium (MPMT) or small (LPLT) cells, configured in either single-cell (one isolated transmitter), MFN (Multiple Frequency Network) or SFN (Single Frequency Network). Some additional signalling is then simply required to inform UEs about broadcast programmes distributed by a given cell or within an SFN-area and to guarantee service continuity between reception areas assigned with a different carrier frequency.

Terrestrial Broadcast as a Service allows operation via both MNO and BNO networks. In the case of MNO operation, the implication is that at least one MNO can have a 5G network already in place and allocate certain capacity in its carriers (e.g. in those carriers with better coverage) to deliver TV/radio services in broadcast mode. For BNO networks, a regular 5G carrier – that is muted at those instances where the MNO would otherwise transmit unicast – or a 100% broadcast carrier can be used.

Conversely to OTT, where an uplink may be needed in order to select a particular service to be received (e.g. accessing a database, website, etc. to retrieve the URL and presentation characteristics of the service), reception of Terrestrial Broadcast services assumes that all the necessary signalling to access a service is provided in the downstream.

Where the service is operated by an MNO network, a receive only mode without the need of registration can be used so that a carrier operated by an MNO can allow services not requiring an MNO subscription to be received alongside potential TV/radio services in non-receive-only broadcast mode. In the BNO network, the receive only mode is considered.

2 Technical requirements for Terrestrial Broadcast operation

Terrestrial Broadcast differs in some respects from the other broadcast modes that exist in LTE/5G and – of course - from the operation of mobile systems. Terrestrial Broadcast in general, but also the link to different ownership scenarios, has some peculiarities that a 5G-System has to cope with.

It should be noted that 3GPP has not yet studied possible enhancements from a system perspective in order to meet the requirements for 5G terrestrial broadcast using the 5GS-based architecture. There is therefore an opportunity to define the operational characteristics of the system. Note that some of the service requirements related to this are also captured in TS 22.261.

2.1 Interaction with Content Service Provider: Ownership scenarios

In case of Terrestrial Broadcast, ownership scenarios of the equipment used for service provision partially differ from mobile systems. Here ownership of the equipment of the Content Service Provider, of the Core Network, of the Access Network and of the UE are relevant:

a) Ownership of the equipment of the Content Service Provider (CSP): In the case of Terrestrial Broadcast, a CSP provides the broadcast service such as “BBC One”, “ZDFinfo” or, “ARTE”, to be distributed via the 5G-network and other distribution paths (e.g. Sat-TV, IP-TV, …). The technical entity that delivers the content of a CSP to the different distribution paths is the play-out center. For this purpose, the 5G-network exposes an xMB-interface to the playout center.
b) Ownership of the Core Network that distributes the content delivered by the play-out center of the CSP to the RAN and its gNBs.
c) Ownership of the Access Network. The Access Network encompasses the RAN and in particular its gNBs. Note, that for Terrestrial Broadcast the owner of the RAN can technically operate its RAN in spectrum bands with either a broadcast allocation or in principle also with a mobile allocation.
d) Ownership of UE, i.e. the end-user, that uses the device to receive/view/listen the content provided by a CSP i.e. a broadcast service.

A 5G-network used for Terrestrial Broadcast technically needs to support different ownerships scenarios. The two most common scenarios are described in the two following subsections.

2.1.1 Classical Scenario

In the classical scenario, the CSP i.e. the broadcast service or broadcast company that owns this service, is also owner of the Access and Core network used for broadcast distribution.

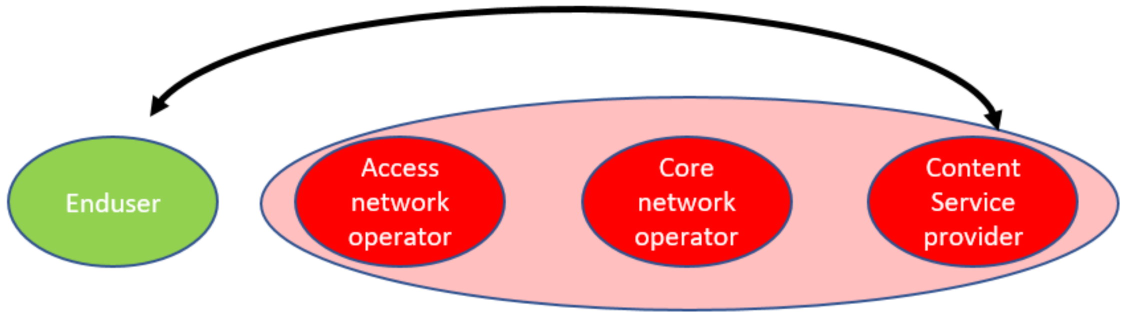


Figure 1: Classical scenario

The license owner for operation of the transmitters of the Access Network is the broadcast company/service that operates the CSP, Core Network and Access Network.

The end-user has a commercial relationship with the broadcast company/service. That means for example, complaints regarding coverage and/or QoS of a broadcast service are targetted at the CSP who has to solve them internally.

2.1.2 Broadcast Network Operator scenario

In the Broadcast Network Operator scenario, the Access Network and Core Network are owned and operated by a separate Broadcast Network Operator (BNO). The CSP owns only the playout-centre.

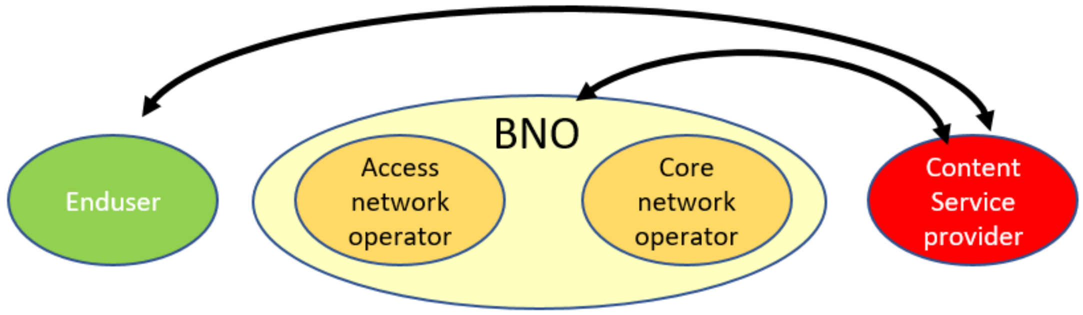


Figure 2: Broadcast Network Operator (BNO) scenario

There are two commercial relationships, one between CSP and end-user and a second one between CSP and BNO. There is no direct commercial relationship between BNO and end-user. The commercial relationship between CSP and BNO will usually include a service level agreement (SLA), that defines e.g. the coverage and the QoS the BNO will provide for a CSP to the end-users and how the CSP can use the infrastructure of BNO e.g. available capacity, supplementary services, options regarding service delivery (e.g. modifications regarding distribution during operation) etc. The commercial relationship between end-user and CSP comprises e.g. decryption key handling and/or payments for content reception.

Regarding the spectrum license to operate the Access Network transmitters, two basic options exist.

a) **The BNO is holder of this license**. In this case the BNO offers certain capacity, coverage, QoS-levels etc. to a CSP (as agreed in an SLA). The BNO in turn will distribute the content of the CSP via spectrum of the BNO. This case is applicable to a situation where e.g. an MNO offers BNO services to a CSP for linear TV services.

b) **The CSP is holder of this license**. This option is comparable to the outsourcing of the AN- and CN-operation to an external company (e.g. Media Broadcast in Germany, Arqiva in UK or Cellnex in Spain). In this case the CSP has significantly stronger influence on the operation and deployment of the AN (transmitter properties, usage of RF-channels/-resources, coverage planning, etc.).

A 5G-System according to the concept of 5G-Xcast shall support the above-mentioned ownership scenarios or combinations thereof. In particular: one Access/Core Network might serve multiple CSPs. i.e. there would be one or multiple instances of xMB-interfaces per XCF and XUF supported in order to meet the scenarios shown below and each xMB-instance connects one play-out centre to a XCF/XUF.

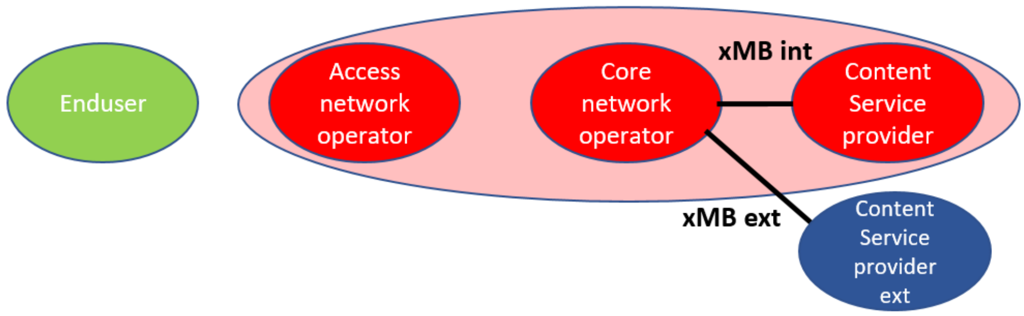


Figure 3: Modification of the classical scenario - Access and Core Network of a CSP is used by an external CSP.

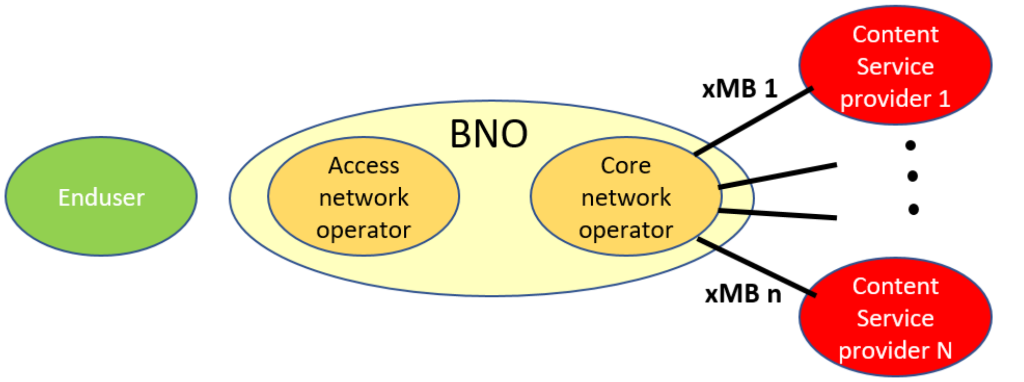


Figure 4: BNO scenario - The infrastructure of the BNO is used by multiple CSPs.

From a standardization point of view, there is no difference between “xMB int” (xMB internal) and “xMB ext” (xMB external). However, the xMB standard might comprise configuration options/parameters that are not applicable for BNO-scenario in Figure 1. In this sense, deployment of xMB as “xMB ext” uses a subset of the xMB standard.

2.2 User access to Terrestrial Broadcast services

2.2.1 Always-on transmission

Terrestrial Broadcast is a service that provides “Always-on transmission” of content. This means a Terrestrial Broadcast transmission lasts usually from days to years. Within this period the configuration e.g. of the distribution area can be changed e.g. to switch temporarily between countrywide content distribution and regional content distribution.

A further implication of “always-on” transmission on the radio interface is that the transmission of the content must be continuously accompanied by broadcast signalling on the radio interface. This signalling ensures that UEs switched on after start of an ongoing transmission can still receive information about Terrestrial Broadcast channels transmitted by a certain gNB or within a certain transmission area by multiple gNBs. Further this signalling allows changes of the configuration to be indicated to receiving UEs (e.g. because of a change from countrywide to regional distribution and vice versa). This continuously signalling is shown in D4.3 section 6 call flow Fig. 3 by the message “27: PTM configuration broadcast”.

2.2.2 Transmission independent of user location and density (ROM)

The number and locations of receiving UEs receiving in the distribution area are unknown; there is no uplink available from the UE to the network. This implies that UEs that want to receive an already ongoing Terrestrial Broadcast service can receive a continuously transmitted signalling (as explained above) to provide them with all relevant information on Terrestrial Broadcast services supported in a cell/SFN-area and optionally in neighbour cells/SFN-areas.

2.3 Terrestrial Broadcast distribution area configuration

2.3.1 Control of distribution area parameters

The CSP shall be able to control the distribution of the content within the coverage area of the BNO to some extent. However, the basic assumption here is that certain technical AN and CN details regarding topology and deployment (gNB-coordinates, antenna characteristics etc.) cannot be altered by a CSP. Since these are usually a result of network planning by the BNO, they influence the content of the SLA and they can usually not be changed easily or quickly.

The SLA can contain multiple sets of RAN and CN configurations in terms of coverage area, transmit powers of gNBs, MCS, used frequency and physical resources etc.. The CSP shall be able to change between those pre-negotiated configurations by means of messages via the xMB-interface (see D4.3 Fig. 3 message “4. HTTP PUT//xmb/v1.0/services/1/sessions/1”). Such modifications shall be possible during ongoing operation.

In the ownership scenarios “Classical scenario” CSPs might require more comprehensive control of the RAN. Therefore, the pre-negotiated configurations might comprise additional parameters such as time interleaving depth, MCS, and perhaps, even broadcast frequencies and transmit powers.

In the ownership scenario “BNO scenario” the CSP has less control over the radio resources. In this scenario, the configurations might be restricted to only certain coverage areas.

The different configurations according to the SLA are assumed to be changed rather seldom. They might be stored within the Network by means of O&M (Operation and Maintenance) commands, while the change between different possible configurations should be possible in a rather dynamic way and should be triggered by the CSP via xMB-interface.

2.3.2 Shape of distribution areas

It shall to be possible that distribution areas for Terrestrial Broadcast can consist of combinations of single cells (operated in MFN-mode) and cell-clusters where each cell-cluster is operated in SFN-mode as shown in Figure 5. Note that the reasons for such an inhomogeneous cell-layout and the use of different frequencies can be, for example, differences in topology/morphology/population-density, cross-border coordination requirements, regional licenses, editorial regions, availability of transmitter sites, etc.

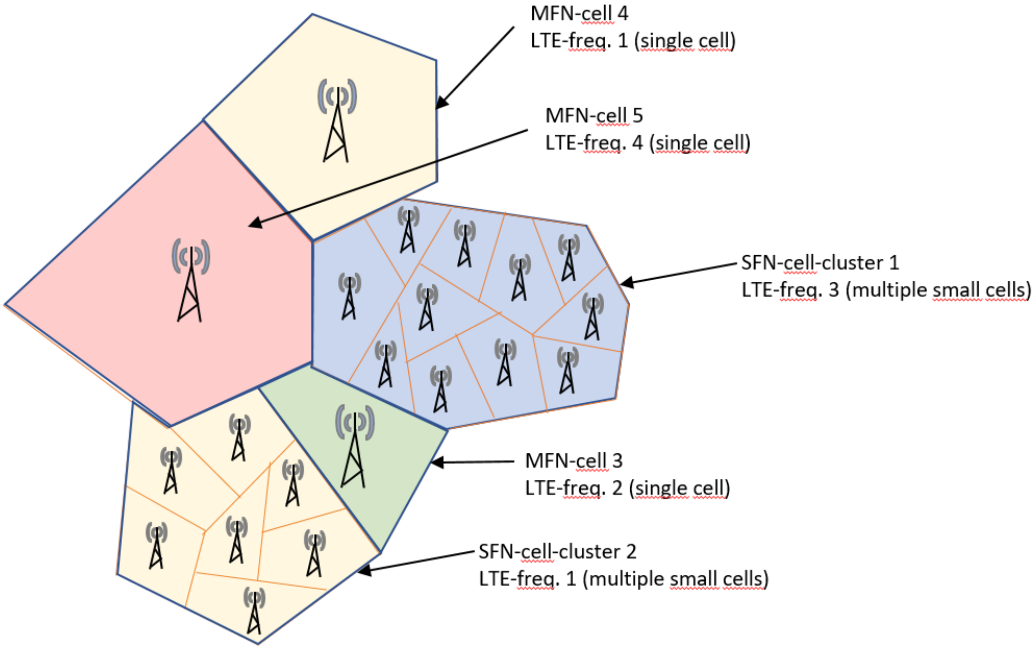


Figure 5: Example of a cell-layout and frequency deployment

2.4 Service Identification and Service Continuity

Terrestrial Broadcast will be received by UEs that are ROM-capable and SIM-free and are consequentially not attached/known to the network/CSP. If an end-user wants to use such a UE to receive specific broadcast services, a mechanism is needed to indicate via the radio interface which broadcast services (e.g. BBC-one, RAI1, ARTE, ZDFneo) are transmitted in the cell/SFN-area the UE camps on.

For this purpose, Programme-IDs are needed,

- that specify a broadcast service in a unique manner worldwide, regionwide or at least within the service area where this service is intended to be provided, i.e. each service of a broadcast company needs to have a unique Programme-ID that enable an easy mapping to the resources carrying the programme in a given carrier or even the identification of the presence of the service in adjacent transmitter areas;
- that are transmitted by each gNB within a list of all available Programme-IDs where this list is sent continuously (e.g. once in 3 seconds) by each gNB in the message “27: PTM configuration broadcast” of D.4.3 Fig. 3;
- that are provided by the CSP via xMB during service establishment in message “4. HTTP PUT//xmb/v1.0/services/1/sessions/1” of D4.3 Fig. 3;
- that are carried through the call flow in D4.3 Fig. 3 down to the gNB to be indicated in the message “27: PTM configuration broadcast” of D.4.3 Fig. 3 and that is linked with user plane content coming from the corresponding CSP (i.e. provide a links to the content in “31: data over PTM” in D4.3 Fig. 3);
- that enable moving UEs to detect in advance (e.g. by adjacent cell measurement/detection), whether a certain broadcast service is also available in a neighbour cell; and,
- that enable moving UEs seamless changes to adjacent cells transmitting the same broadcast service.

This Programme-ID is comparable to the Service-ID of DAB (see e.g. [7]).

3 5G System Configuration and Mechanisms for Terrestrial Broadcast Service Provision

3.1 Basic steps to configure Terrestrial Broadcast from CSP to Core Network

Essential steps (non-technical and technical) to deliver a Terrestrial Broadcast service are:

a) Negotiation of a service level agreement (SLA) between CSP and BNO (this is in the "classical scenario" a company internal process). In this iterative process issues of the service provision are agreed such as.:
   - Does the distribution area desired by the CSP fit with the coverage area of the RAN of the BNO?
   - Which QoS can be provided?
   - Which frequencies can be used and under which conditions; who are the license holders?

   As a result, this SLA will contain one or a number of configurations of the RAN that are needed to achieve certain coverage objectives of the CSP. Such a configuration determines, which gNBs are needed for the distribution of the broadcast service, the necessary transmit power of each gNB (broadcast transmitters), which the MCS shall be used and potentially as well which physical resources on the radio interface shall be used when e.g. the CSP is owner of the spectrum license and/or if SFN-operation is intended. In this sense, these configurations are also results of prior planning of the Terrestrial Broadcast network to achieve a certain level of coverage quality (e.g. geographical areas for indoor, for outdoor-street-level or for outdoor-roof-top coverage etc.).

   The configuration options of the SLA are stored in the CN by O&M, preferably they are stored in the XCF.

b) Establish the xMB interface between the play-out centre of the CSP and the Core Network of the BNO.

c) Selection of an appropriate configuration by sending via xMB the corresponding configuration number as agreed in the SLA from the CSP to the BNO.

d) This triggers the XCF to configure/reconfigure the CN and the RAN according to the selected configuration option i.e.
   - configuration of the agreed selection of gNBs with the agreed parameters (transmit power, MCS, physical resources, Programme-IDs, content of Service Announcement messages, …). Note that some of these parameters can be configured via O&M and selected by means of indices or specific strings via xMB.
   - establishing the IP-multicast paths to the gNBs

   For the sake of flexibility and scalability, each broadcast service (TV or radio service) present in a 5G carrier may be configured under different capacity and coverage criteria (e.g. each service may address a different service area with different MCS index and resource allocation).

e) The confirmation of the finalization of the network resource configuration

f) The start of the downstream content of the broadcast service from the playout centre of the CSP via the user plane of xMB to and through the Core Network down to the gNBs and transmission of this content on the 5G Terrestrial Broadcast radio interface.

By repetition of step c) a change to another agreed configuration option is possible. This will trigger corresponding actions according to steps d) and e) and allows modifications to where and how the broadcast content is transmitted via the radio interface. Such modifications might change all cells or only selected cells regarding the physical resources used, the transmit power, MCS, etc. Such modification shall not interrupt the transmission of content via the radio interface (except in those cells affected by such a modification).

In particular, the details of steps c) to f) are shown in the call flow "Resource management for point-to-multipoint services" of D4.3 in Fig. 3 "Network resource allocation for broadcast", which is also included here for reference.

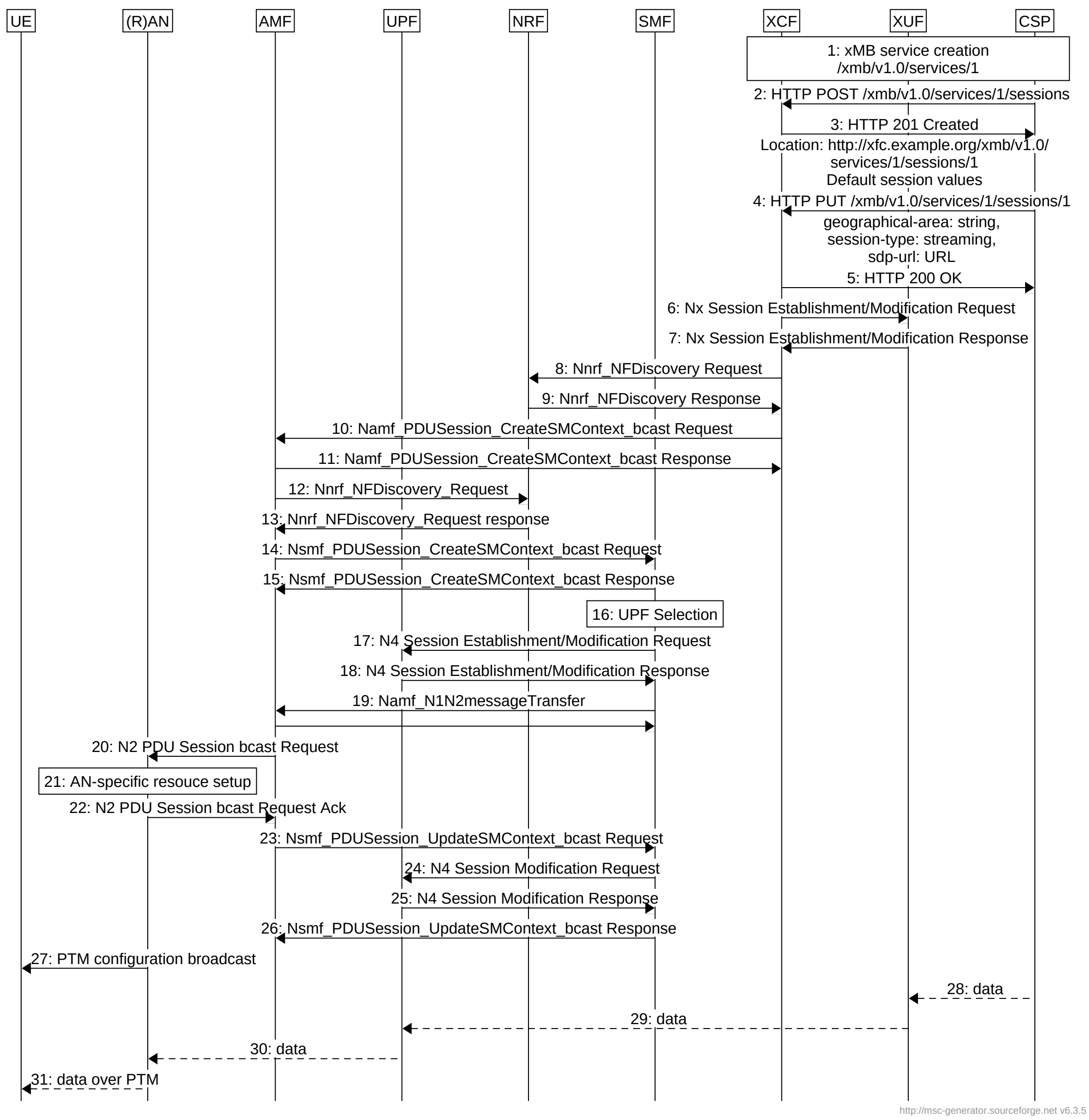


Figure 6 Network resource allocation for Terrestrial Broadcast

3.2 Simplified 5G-System architecture for Terrestrial Broadcast: NFV and Network Slicing

The message flow in D4.3 Fig. 3 indicates that for Terrestrial Broadcast only a subset of the functions of a complete 5G architecture is needed. Terrestrial Broadcast does not require additional functions in the Access or Core Network.

The main reason for this simplification is that the UEs remain completely unknown to the network (no registration, no activity counting etc.) and that the network mainly serves the purpose to only distribute the content from one source (the CSP) to many gNBs, where it is continuously broadcast at the radio interface.

Figure 7 shows the reduced network architecture. (The omitted functions are indicated in grey).

The following network functions are still needed:

- The Xcast Control Function (XCF): This translates the configuration selected by the CSP (in particular the geographical description of the distribution area into a list of gNBs, triggers the configuration of the IP- and IP-multicast distribution paths from xMB via XUF to the gNBs, and controls the configuration of the relevant gNBs (this includes the provision of the Programme-ID to the gNB in case gNB configures the service announcement).
- Session Management Function (SMF): This functionality supports the configuration of the user plane from XUF to the RAN. In the case of Terrestrial Broadcast, the SMF functionalities can potentially be provided by the XCF, therefore replacing the SMF.
- User Plane Function (UPF): This supports the transfer of User Plane data from XUF to the RAN. In the event that the gNBs directly receive the content by listening to the IP-multicast address used by the XUF for a specific Terrestrial Broadcast session it can be omitted.
- Network Repository Function (NRF) and Access and Mobility Management Function (AMF): These are needed to configure the distribution areas (i.e. the needed gNBs) accordingly (cmp. D4.3 Fig. 3). These functions facilitate the reuse of standardized 3GPP functionality for Terrestrial Broadcast.
- Radio Access Network (RAN): This emits both, the linear content of the Terrestrial Broadcast and the required signalling information, according to the selected configuration.
- User Equipment (UE): This:
    - displays on basis of the received Programme-IDs the broadcast services available in the cell/SFN-area the UE is camping on,
    - tunes on basis of user selection regarding Programme-ID to the corresponding physical resources bearing the content of the CSP associated with this Programme-ID; and,
    - remains fully unknown to the network and receives only.
- Network Exposure Function (NEF): This function might be required in the case of the BNO scenario or in case of an external CSP in the classical scenario to guarantee a trusted connection between XCF/XUF and the playout centre of the CSP.

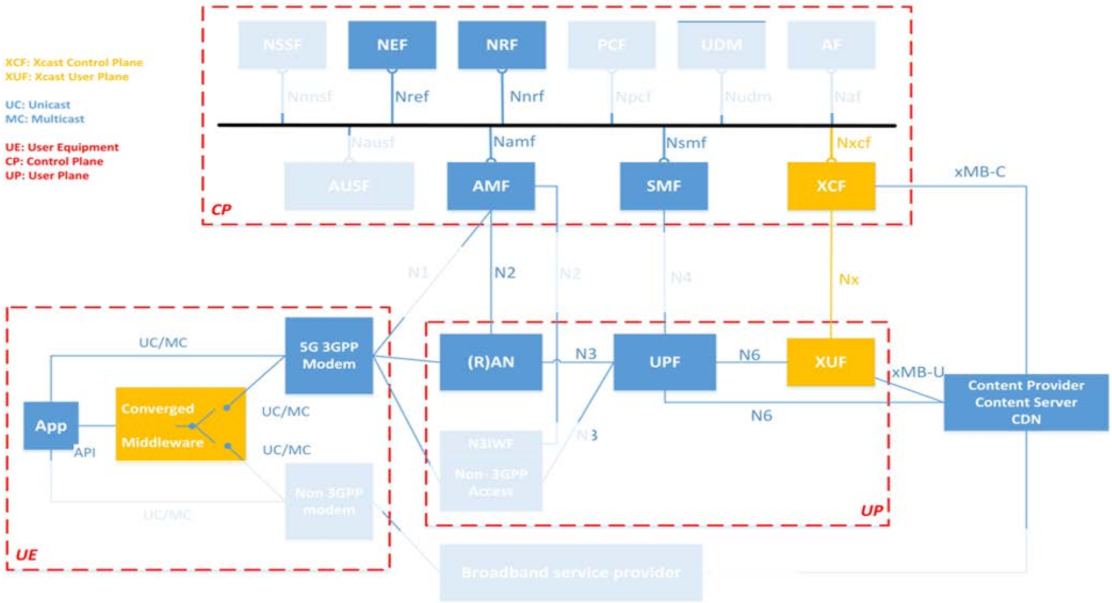


Figure 7: Reduced 5G System Architecture for Terrestrial Broadcast

3.3 The roles of NFV and Network Slicing

5G introduces new architecture paradigms with Network Function Virtualization (NFV) as a key enabler for a scalable deployment of software network functions in general purpose platforms. On top, Network Slicing provides the means to guarantee a given end-user QoS for certain applications and services by management and control of the RAN and Core Network resources and infrastructure.

The architecture for terrestrial broadcast can be implemented as a network slice as depicted in Figure 8. The network slice for Terrestrial Broadcast needs to comprise the functions listed in section 3.2.

Depending on the ownership of the Access Network and in particular the gNBs two basic solutions seem to be of major interest:

1. The RAN for Terrestrial Broadcast is owned by the broadcast company (classical scenario in section 2.1.1) or is at least operated under the license of a broadcast company (e.g. BNO scenario in section 2.1.1 option b))
   In this case the network slice is connected to a separate RAN (in Figure 8 symbolized by "RAT4") that is solely used for Terrestrial Broadcast transmission. The system is deployed in a spectrum used exclusively for broadcast.

2. The RAN is not owned by a broadcast company and the frequency license is owned by an MNO (BNO scenario in sect. 2.1.1 option a))
   In this case the network slice for Terrestrial Broadcast is connected to the RAN/gNBs of the MNO (in Figure 8 symbolized by "RAT2"), the Terrestrial Broadcast is transmitted in spectrum with a mobile license and mobile spectrum resources unused for Terrestrial Broadcast (e.g. uplink resources) can be used for unicast mobile services.
   This solution does not necessarily require a separate network slice for Terrestrial Broadcast. As Terrestrial Broadcast requires a subset of network functions of a regular 5G network, Terrestrial Broadcast functionalities could alternatively be provided by the regular 5G network or a regular 5G network slice.

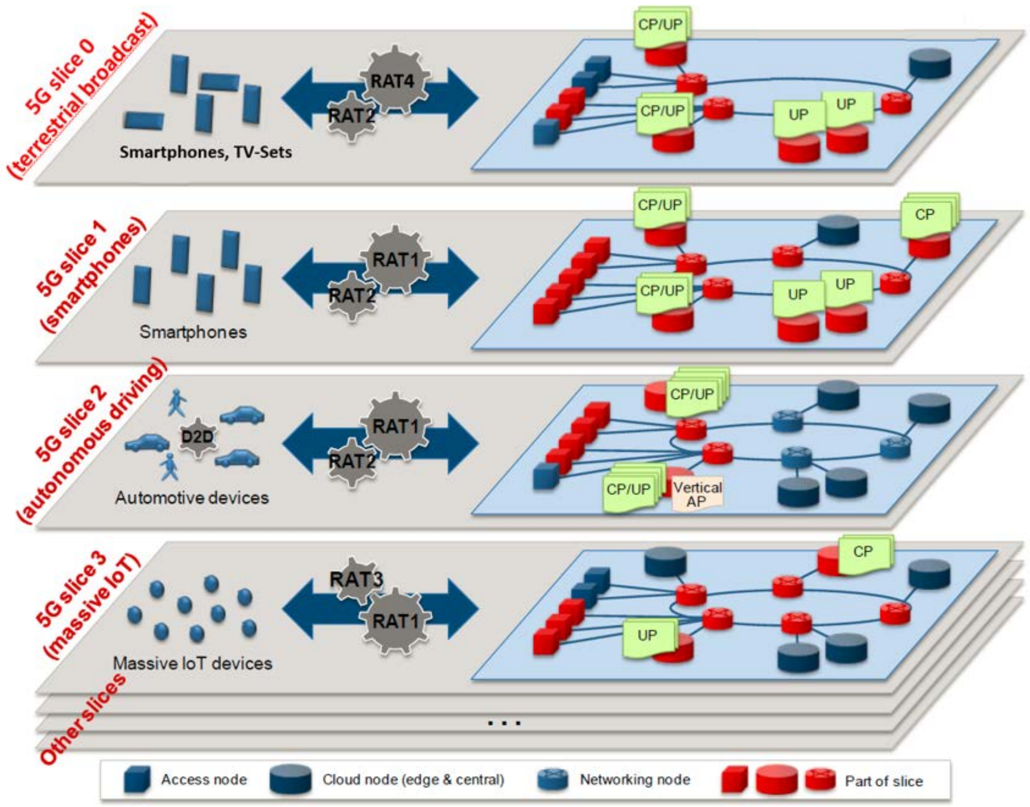


Figure 8: 5G network slices including a network slice for Terrestrial Broadcast

3.4 RAN Architecture and Procedures

The RAN architecture and the related procedures for Terrestrial Broadcast are based on those existing to enable multicast/broadcast functionalities in 5G as defined in 5G-Xcast. As explained in D3.3 [8], the RMA (RAN Multicast Area) is configured in terms of a Terrestrial Broadcast Service Area (TB-SA) which provides a mapping between the gnB (broadcast stations) available to transmit a particular TV/radio service and the amount of time/frequency resources reserved for such purpose. A given TB-SA is constituted by a list of cells that are provided via O&M. Via xMB, the service provider can select which TB-SA a service will employ. This is done by means of an index (TB-SA ID). The XCF translates TB-SA indexes to the actual identifiers of the gNBs in use.

Associated with each broadcast service, the MCS index that fulfils the robustness (coverage) and data rate requirements of the SLA is indicated together with scheduling information in terms of required time/frequency resources for the given data rate (e.g. initial and final PRB). An admission control procedure will determine the allocation of a new broadcast service according to the amount of available resources in the carrier for the allocation of Terrestrial Broadcast service (as indicated per TB SA) and the amount of required resources per service.

In this way, it is possible to fill a 5G-NR carrier with a series of programmes each one with a different target coverage and data rate. The system is prepared for operation under different bandwidth conditions. A regular approach would be to employ multiple carriers per transmitter, therefore extending the complete service offering over a series of RF channels and each one addressing, if necessary, different coverage configurations (local transmission, regional SFN, nationwide SFN…). It would also be possible to configure a high-bandwidth carrier with different numerologies multiplexed within it.

In the example below, one transmitter (central cell) is delivering a series of services with different coverage targets

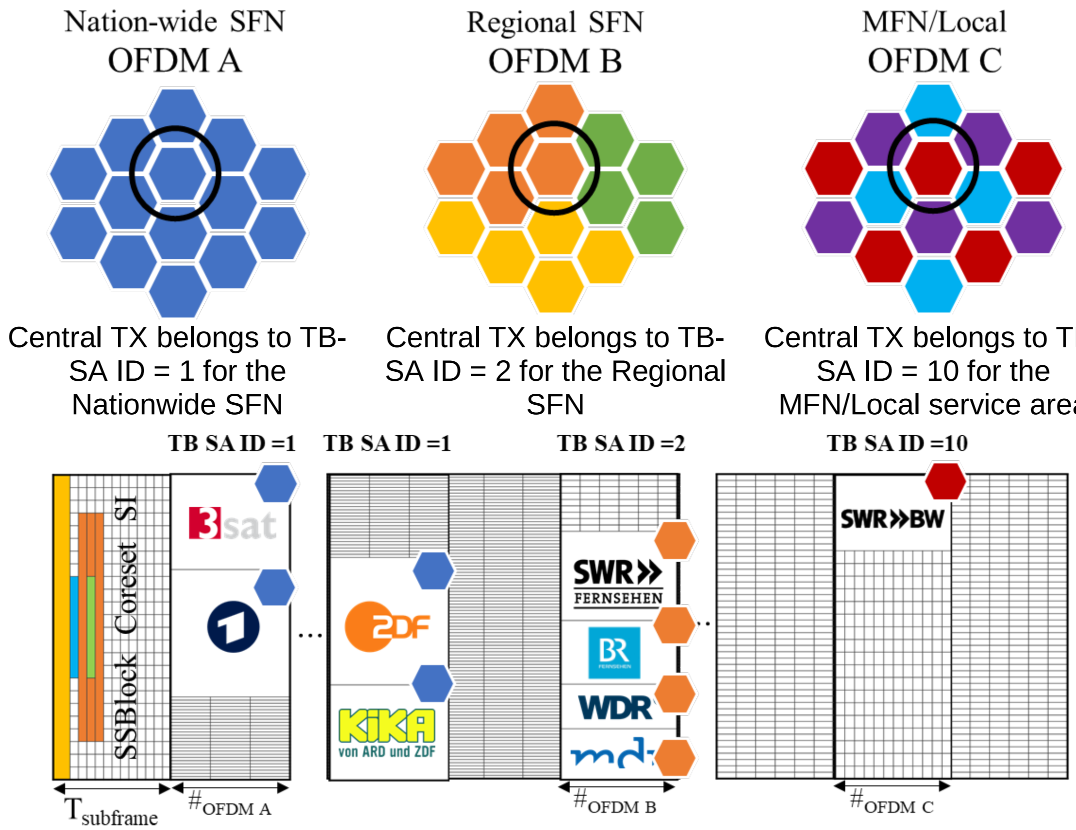


Figure 9: Three deployments consisting of a nation-wide SFN, a regional SFN and a single cell transmitter and their relation to Terrestrial Broadcast Service Areas.

3.5 Physical Layer Signaling and Service Discovery without uplink involvement

The general assumption is that UEs for Terrestrial Broadcast reception

1. can operate in receive-only mode (ROM),
2. don't need to have a SIM ("SIM-free") and
3. don't need to attach to any particular transmitter ("transmitter-free" or "TX-free").

After switch-on, such UEs shall be capable to display within e.g. 3 seconds a list of all broadcast services available in the cell it is camping on. In case of switch-on and resumption of the reception of an earlier used broadcast service (before switch-off), the UE shall be capable to continue the replay of this broadcast service within e.g. 5 seconds after switch-on, if this broadcast service is available in the location the UE is switched on. If the location of the UE is covered by multiple BNOs the display of all available broadcast services shall happen a reasonable amount of time, as for example when scanning a list of FM/DAB or DVB-T/T2 services.

This behaviour requires:

- that the regular 3GPP procedures for network selection are reused;
- that the relevant Terrestrial Broadcast signalling is broadcast and placed in a pre-defined and specific band or bands (for normal UEs the network selection can be quite time-consuming because it has to search for suitable networks over a wide range of spectrum bands – therefore UEs shall search the specific broadcast

signalling only in a series of bands where Terrestrial Broadcast services are suitable to be transmitted (e.g. preferably in the UHF-band 470-694MHz but not restricted to it);

- that each gNB transmitting broadcast services repeats the complete Service Announcement messages indicating all Terrestrial Broadcast services transmitted in the cell, for example, at least once within 2 seconds; and
- that the entire “Cell Acquisition and Service Detection signalling” on the radio interface including the Service Announcements is optimized, for example, easy and quick to find and requiring minimal processing effort to decode.

The “Cell Acquisition and Service Detection signalling” reuses to some extent LTE- and 5G-procedures and comprise the following steps:

1. synchronization to the carrier frequency and radio interface subframe by decoding PSS and SSS)
2. reception of the PBCH and reading the MIB (Master Information Block).
3. Reading PCFICH, PDCCH etc. to read the SIB1, which indicates further, available SIBs
4. For Terrestrial Broadcast existing SIB2 and SIB13 in LTE are of interest but need a modification/enhancement to indicate the PDSCH that contains the User Service Definition (USD). Alternatively, SIB1 needs to indicate a new, TB-specific SIBx that indicate the resources of the PDSCH carrying the USD.
5. Optionally, the PDSCH from step 4 above can provide a list of broadcast service availabilities in adjacent cells/SFN-areas to enable seamless reception in case of cell/SFN-area changes.

Note that what is proposed here is to consider an entry point (bootstrap) in the 5G-NR carrier for an easy acquisition of the Terrestrial Broadcast services transmitted within it. Two options may arise:

- To consider that each Terrestrial Broadcast service can have an independent bootstrap (e.g. each service will have each associated RNTI, MIC, DCI, SIB information); or,
- To consider that there is a single bootstrap for Terrestrial Broadcast services (or one per carrier or BWP) which points to a USD list of services which expands the information regarding the resource allocation and configuration of each Terrestrial Broadcast service present in the current cell. In this case a common terrestrial broadcast RNTI (TB-RNTI) could be allocated.

The USD is a list, that contains for each broadcast service of this cell an information vector that provides at least:

- the Programme-ID of each broadcast service;
- the position and the modulation/coding of the physical resources of this broadcast service in terms of e.g. Frequency Channel Number (EARFCN) and Downlink Control Indicator (DCI);
- further parameters for decoding of the data stream of the broadcast service (e.g. G-RNTI); and,
- perhaps a human-readable name of the broadcast service.

Progr-ID	EARFCN	Physical Resource	Specific Info	Clear Name	…
0A2Eh	# 13	DCI = aaa	G-RNTI = xxx	ZDFneo	…
02B3h	# 13	DCI = bbb	G-RNTI = yyy	Bayern1	…

22CFh	# 14	DCI = ccc	G-RNTI = zzz	BBC-One	…
…	…	…	…	…	…

Figure 10: Example of a USD-list

It is important, that the USD-list can contain information on both, broadcast services transmitted on single-cell/MFN subframes and SFN-subframes. This facilitates the identification of available broadcast services by the UEs because the display of all available broadcast services does not require additional decoding of e.g. PMCHs in LTE. With respect to SC-PTM operation in LTE this USD-list provides the functionality of SC-MCCH within the DL-SCH.

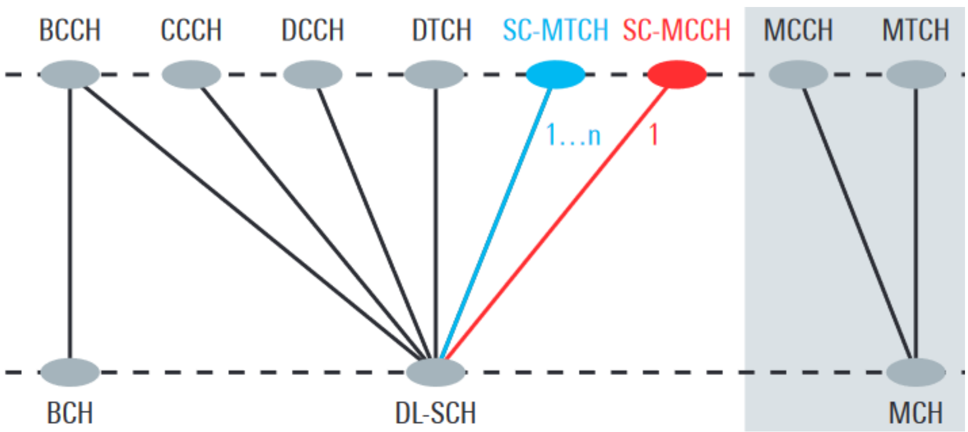


Figure 11: Example of SC-PTM mapping in LTE

3.6 Air-Interface Design

The design of the air interface of an MBMS system based on 5G New Radio (NR) is included in Deliverable D3.2 [6]. The design extends the recent 5G-NR developed in 3GPP Release 15 and Release 16 to enable mixed-mode multicast/broadcast operation and the inclusion of Terrestrial Broadcast services within the 5G-NR carrier. The design does not necessarily require a split between a mixed mode carrier containing unicast/multicast/broadcast and a dedicated carrier as the latter is simply derived from the allocation of 100% of resources to Terrestrial Broadcast services (in a similar way as when a single user or several users consume all the resources of a 5G-NR downlink carrier).

For the single-cell or MFN configurations, the physical layer design that has been outlined has a minimal impact with respect to unicast. Existing synchronization and acquisition mechanisms could be reused with only minor changes. Linear TV/radio services data can be allocated by means of a group identifier (G-RNTI) or a specific TB-RNTI in a similar fashion to the way unicast data is scheduled. LPLT (small cells) as well as HPHT (large cells) stations can be employed. The NR carrier may be used to allocate up to 100% broadcast data multiplexed in both time and frequency domains with high granularity and without major constraints (by reusing the existing procedures for unicast).

SFN may be enabled by extending the single-cell mode. The non-optimal design of LTE eMBMS RAN for the provision of Terrestrial Broadcast services in typical scenarios was already identified in [9]. The solution proposed by the authors as well as recent 3GPP contributions such as in [10] have been taken into consideration for the definition of potential numerologies for Terrestrial Broadcast in 5G-NR, which would need to be accompanied by a proper design of reference signals. An example of potential numerologies is included in the following table.

Table 2: Potential 5G-NR numerologies for Terrestrial Broadcast

µ	Δ_f (Hz)	TU (µs)	CP Fraction	TCP (µs)	TS (ms)	SC/RB	ISD (km)
0	15000	66.67	~7%	4.7/5.1	0.07	12	1.4
0	15000	66.67	20%	16.67	0.08	12	5
-1	7500	133.33	20%	33.33	0.17	24	10
-2	3750	266.67	20%	66.67	0.33	48	20
-	2500	400.00	20%	100.00	0.50	72	30
-3	1875	533.33	20%	133.33	0.67	96	40
-	1250	800.00	20%	200.00	1.0	144	60
-	625	1600.00	20%	400.00	2.0	288	120
-	3333	300.00	10%	33.33	0.33	54	10
-	2045.45	488.88	2.22%	11.11	0.50	88	3.3
-	1022.72	977.78	2.22%	22.22	1.0	176	6.6
-	511.36	1955.56	2.22%	44.44	2.0	352	13.2
-	416.67	2400	4%	100	2.5	432	30
-	208.33	4800	4%	200	5.0	864	60
-	104.67	9600	4%	400	10.0	1728	120
-	217.39	4600	8%	400	5.0	828	120

The definition of numerologies for integrating SFN deployments with large inter-site distance transmitters may require a more complex design in terms of receiver processing and a corresponding trade-off between mobility and SFN coverage. Note also that MFN numerologies may also be optimized to reduce capacity overheads. It is also important to note that although it is desirable from a deployment perspective to have as much flexibility as possible, consideration should also be given to the potential receiver complexity (and related testing) that may impose limitations on the maximum number of numerology options finally included in the specifications.

Based on 5G NR, the system outlined in D3.2 may outperform the existing LTE-based 5G Terrestrial Broadcast system. The design takes into account different reception scenarios targeting high speed (at the expense of capacity overhead) and static reception (maximizing SFN efficiency and capacity). The use of the new physical layer features of 5G-NR such as new LDPC and Polar codes, increased bandwidth efficiency and efficient numerology multiplexing permits the configuration of new transmission mechanisms that outperform LTE.

5G-NR allows up to 7.2% higher bandwidth utilization compared with LTE. With the use of bandwidth parts with different numerologies, a single wideband carrier can multiplex services intended for different reception conditions and different coverage areas, including local, regional SFN and nation-wide SFN. Data channels can benefit from a slight reduction of the CNR threshold while the gains in term of performance of the control channels are more noticeable thanks to the possibility of e.g. increasing aggregation levels.

In terms of signalling, the existing control channels for unicast may already enable reduced overhead with respect to the CAS in LTE-based 5G Terrestrial Broadcast and may not require any modification since they are more flexible in terms of resource allocation and periodicity. In terms of overheads, a skilful design may be possible to maximize capacity by an adequate CP and useful OFDM symbol duration. Common techniques used in other standards, such as physical layer time interleaving for improved robustness in mobile environments, would also be of benefit, should they be adopted by 5G-NR Terrestrial Broadcast.

More information about this approach can be found in [11].

4 Conclusions

5G has a special significance for Terrestrial Broadcast, because it will facilitate reception of linear TV and radio services in UEs (smartphones, tablets or any other kind of devices with a 5G chipset). The main reason is that the need for dual/multiple receiver implementations in UEs (e.g. 5G & DVB-T2 or 5G & DAB+ etc.) is avoided. Furthermore, Terrestrial Broadcast in 5G can build on the 5G Multicast/Broadcast (also called mixed-mode) capabilities to be included in 5GS as a configuration option. In other words, Terrestrial Broadcast can benefit from the architecture defined for multicast/broadcast functionalities without the need of an independent and dedicated architecture.

The SC-PTM mode using DL-SCHs is considered as the more promising option for a first introduction of Terrestrial Broadcast services in 5G since SC-PTM:

1. reuses the framework already available for unicast transmissions (users are treated as TV/radio services) and mixed-mode multicast/broadcast;
2. permits high flexibility in terms of capacity allocation to broadcast services (not restricted to entire 5G subframes);
3. permits high granularity in terms of PRBs per broadcast service i.e. easier to use for a mix of high bitrate services (e.g. TV) and low bitrate services (e.g. audio broadcast);
4. avoids the use of multiplexes of multiple broadcast services; and
5. permits “partial SFN-operation” in case of synchronized gNBs carrying the same broadcast services in adjacent cells.

However, regarding SFN operation, it should be noted that the existing numerologies in NR may only be suitable for Terrestrial Broadcast operation in small-cells (cellular networks) with short inter-site distances due to the lack of a sufficiently long CP to enable large SFN areas and large a delay spread at the receiver. The short CP may be unable to provide adequate performance for HPHT stations due to multipath self-interference from the network. This will depend on the deployment scenario and on the target data rate of the service (e.g. radio services with low data rate may be configured with a robust MCS to cope a low SNR resulting from the multipath).

A careful design of the air-interface is required in order to enable operation in multiple types of networks and taking into account complexity issues at the receiver and avoiding high deviations from the regular unicast or 5G multicast/broadcast design in order to minimize standardization and receiver implementation effort.

The 5G-Xcast solution proposes a global approach for Terrestrial Broadcast distribution where linear TV and radio services can be received in receive-only mode (and free-to-air) with the possibility to be:

- allocated into 5G-NR carriers (delivering both unicast and Terrestrial Broadcast data) and operated via MNO networks; and/or
- allocated into 5G-NR carriers without unicast traffic (i.e 100% Terrestrial Broadcast) and, therefore, with the possibility to also be operated via BNO networks.

A Current Approach to Terrestrial Broadcast in 3GPP

A.1 EnTV/FeMBMS (LTE-based 5G Terrestrial Broadcast) Standardization Activities within 5G-Xcast

Terrestrial Broadcast, as a 3GPP use case, was first addressed in LTE Advanced Pro 3GPP Release (Rel-) 14 in which the Multimedia Broadcast Multicast Service (MBMS) system was enhanced to operate in a dedicated mode for the delivery of linear broadcast services (i.e. radio and TV), fulfilling a wide set of requirements input by the broadcast industry.

3GPP's Enhancements for TV ("EnTV") study item proposed several enhancements resulting in a further evolution of eMBMS during Rel-14. In order to leverage the well-established and proven LTE ecosystem, it was decided to base the system on the pre-existing LTE Advanced Pro specifications with enhancements being made as necessary in order to fulfill the requirements. Enhancements made to the system architecture comprise:

(i) the xMB interface through which broadcasters can establish the control and data information of audio-visual services;
(ii) a new Application Programing Interface (API) for developers to simplify access to eMBMS procedures in the User Equipment (UE);
(iii) the support of multiple media codecs and formats;
(iv) a transparent delivery mode to support native content formats over IP without transcoding (e.g. reusing existing MPEG-2 Transport Streams and compatible equipment);
(v) the support of shared eMBMS broadcast by aggregating different eMBMS networks into a common distribution platform; and
(vi) the receive-only mode (ROM), which enables devices to receive broadcast content with no need for uplink capabilities, SIM cards or network subscriptions – i.e. free-to-air reception.

From the radio layer point of view the most significant enhancements are:

(i) the possibility to establish dedicated eMBMS carriers that allocate up to 100% of the radio resources to Terrestrial Broadcast (i.e. with no frequency or time multiplexing with unicast resources in the same frame), self-contained signaling and system information in the downlink;
(ii) a new, reduced overhead subframe containing no unicast control region; and
(iii) the support of larger inter-site distances in SFN (Single Frequency Networks) reaching higher spectral efficiency with a new numerology – 1.25 kHz subcarrier spacing (SCS) and 200 µs cyclic prefix (CP).

The new numerology changes are the most significant as the longer OFDM symbol duration, occupying one subframe, made it necessary to design a new subframe structure, known as the CAS (Cell Acquisition Subframe), to allocate the synchronization and control channels, transmitted with much reduced periodicity (one in every forty subframes).

These changes led to a system similar in function to other Digital Terrestrial Broadcast systems such as DVB-T/T2, ATSC 3.0 or DAB/DAB+. In addition to broadcast content, mobile broadband subscribers who have a SIM card can enjoy enriched service offerings when combined with independent unicast for interactivity, in a similar way to conventional HbbTV (Hybrid Broadcast Broadband TV) sets. The introduction of a ROM and the new framing and numerology options may make eMBMS suitable for use with conventional broadcast infrastructure (including high, medium and low power sites).

In June 2018, 3GPP held the RAN plenary meeting in La Jolla (USA), where the final scope of Release 16 study items and work items was defined. One of the topics that 5G-Xcast is following closely is the multicast/broadcast support for Release 16.

There have been earlier attempts to introduce a Study Item on 5G multicast/broadcast by several 3GPP members in RAN (Samsung, Qualcomm, EBU, LG), and recently in SA4 (Huawei). But these proposals were postponed due to higher priority Work and Study Items in Release 15.

Qualcomm acted as a moderator of the topic 5G multicast/broadcast between RAN#79 and RAN #80.

In RAN #79, it was decided to split the broadcast work into two tracks:

- **Terrestrial Broadcast**: with a notion of a downlink-only, 'large area coverage up to nation-wide' broadcast on dedicated spectrum, e.g. "TV-like" distribution of content; and
- **Mixed mode multicasting**: notion of downlink multicast/broadcast with the potential to leverage downlink unicast and/or uplink unicast, with configurable/dynamic coverage ranging between a single cell to a large area and multiplexed and possibly seamlessly switched with unicast traffic.

Between RAN#79 and RAN #80, the exact scope of the two study items was defined as follows.

Mixed mode multicasting: In this track, it was proposed to study the equivalent of MBMS into New Radio (NR). In this mode, broadcast will be supported, but coexist with unicast and in a mix of downlink and uplink. The broadcast transmission area will be moderate and dynamically configurable of a one to few cells.

Mixed mode is expected to have a high commonality with unicast, i.e. a common physical layer flexible design to accommodate for different types of broadcast (single cell to large areas). Finally, the mixed mode multicasting design should take into account different use cases such as IoT (Internet-of-Things), V2X and public safety.

Terrestrial Broadcast: It was proposed to use LTE EnTV Release 14 as a basis. This restricts the study to the following scope: a broadcast and downlink only scope with large and static transmission areas. The transmission area could be nationwide or cover a large number of cells. The objective of the study item is to define the enhancements needed to meet 5G broadcast requirements with LTE-based eMBMS specified in TR 38.913, Clause 9.1. Additional requirements from TS 22.261 will also be considered, if needed.

The mixed mode proposal, contained in document RP-180669, was not approved due to the lack of time units for NR studies. It is expected that this proposal will be considered in the future for Release 17 and beyond.

The Terrestrial Broadcast proposal is contained in document RP-181342. The proposal gathered a lot of support. In total, it was supported by 24 3GPP members. The proposal was approved and the timeline was defined in RP-181486. There are two phases: the study item phase (until RAN1#96), that will focus on carrying a gap analysis between the current LTE solution and the 5G requirements, and the work item phase (until RAN#99) that will propose the enhancement to the RAN solution in order to meet those requirements.

The study item in 3GPP Rel-16 has evaluated the ability of eMBMS to support SFN of cells with coverage radii of up to 100 km (implying even longer CP) and mobile reception with speeds up to 250 km/h (large SCS). A wider range of numerologies, supporting multiple network topologies, capacity improvements from longer symbol durations (which reduce CP overheads), new reference signals (RS) and greater bandwidth occupancy were also in the scope of the study. The benefits of time interleaving and LDM (Layered Division Multiplexing), also known as MUST (Multiuser Superposition Transmission), were also taken into consideration. The signal acquisition and synchronization procedures were also evaluated as the existing numerology mismatch between data and control channels for large SFNs may lead to coverage issues as reported in D3.2 [6].

The study item phase concluded (see the report: TR 36.776 Study on LTE-based 5G Terrestrial Broadcast) that changes in Rel14 are necessary in order to support two main features:

- the efficient integration of HPHT (high-power high-tower) broadcast infrastructure for large area SFN Coverage, targeting roof-top reception.
- high speed reception from medium-scale SFN areas, which may become relevant to provide broadcast services to car-mounted receivers or even high speed trains.

A new Work Item has been stablished to standardize solutions (WID proposal for LTE-based 5G Terrestrial Broadcast).

From 5G-Xcast perspective, EBU/BBC/IRT have contributed to the standardization work in 3GPP with the following inputs which are attached as Annex B.

RAN1#94bis (Chengdu, China):
• R1-1810319 – Public service broadcaster requirements and background information relevant to LTE-based 5G Terrestrial Broadcast
• R1-1811588 – Scenarios and simulation assumptions for the LTE based terrestrial broadcast gap analysis

RAN1#95 (Spokane, US):
• R1-1812430 – Evaluation Results for LTE-Based 5G Terrestrial Broadcasting

RAN1#96 (Athens, Greece):
• R1-1903284 – Evaluation Results for LTE-Based 5G Terrestrial Broadcasting

RAN1#96bis (Xi'an, China):
• R1-1905330 – Network Simulations Regarding the Performance of the CAS
• R1-1905331 – Information For Time Variation Models

RAN1#97 (Reno, US):
• R1-1906634 – Network Simulations Incorporating Time Variation for the CAS
• R1-1907093 – Spectral Efficiency of New Numerologies for Rooftop Reception

B 3GPP Inputs

3GPP TSG RAN WG1 Meeting #94-Bis R1-1810319

Chengdu, China 08th - 12th October 2018

Agenda item: **6.2.4.1**

Source: EBU, BBC, IRT

Title: Public service broadcaster **r**equirements and background information relevant to LTE-based 5G Terrestrial Broadcast

Document for: Discussion

1 Introduction

This document identifies the broadcast requirements described in TR 38.913 that are relevant for dedicated terrestrial broadcast networks and for which Rel-14 LTE based eMBMS requires further evaluation, particularly with respect to the delivery of Public Service Broadcaster (PSB) content. Background information, relevant to the identified requirements, has also been provided about typical PSB broadcasting scenarios. A series of observations about the requirements and scenarios have then been made which are intended to inform the development of scenarios and simulation assumptions for the evaluation process.

2 Relevant Next Generation Requirements

The relevant requirements presented in this document from Clause 9.1 TR 38.913 are as follows:

- *The new RAT shall make it possible to cover large geographical areas up to the size of an entire country in SFN mode with network synchronization and shall allow cell radii of up to 100 km if required to facilitate that objective. It shall also support local, regional and national broadcast areas;*

- *The new RAT shall support Multicast/Broadcast services for fixed, portable and mobile UEs. Mobility up to 250 km/h shall be supported; and*

- *The new RAT shall leverage usage of RAN equipment (hard- and software) including e.g. multi-antenna capabilities (e.g. MIMO) to improve Multicast/Broadcast capacity and reliability.*

In the following clauses, each of these requirements is addressed in turn:

3 Coverage of Large Geographical Areas

3.1 Public Service Broadcaster Terrestrial TV Commitments

Public service broadcasters (PSB) normally have commitments to provide near-universal population coverage. For example, in the United Kingdom the BBC has an agreement with Ofcom, the communications regulator, that it is committed to provide roof-top reception of digital terrestrial television (DTT) to 98.5% of households in rural and urban areas alike.

Observation 1: Public service broadcasters typically have near-universal coverage requirements

3.2 Background Information for Terrestrial Broadcasting Networks

Broadcasters usually fulfil their DTT coverage commitments with networks designed to provide reception to fixed rooftop antennas. Typically these networks are made up of transmitter stations with a wide spread in values for attributes such as effective transmitting heights, radiated powers and inter-site distances. At one end of the scale a 'core' network of main high power high tower (HPHT) stations will normally provide wide area coverage to the majority of the population. These stations will have effective radiated powers (ERP) in the order of 20 to 200kW with masts of around 200m to 300m high. At the other end of the scale, smaller stations, some with ERPs of less than 1W will provide coverage for local deficiencies caused, for example, by local terrain screening. These transmitters typically have masts in the order of 10 to 30m high. In between these two ends of the spectrum, a number of transmitters ranging from below 100W to above 10kW will make up the remainder of the network with masts of variable heights spread over the range of the low and high power transmitters.

Observation 2: HPHT terrestrial broadcast networks are formed of disparate transmitters with a wide range of characteristics including non-uniform ISDs, transmitter heights and radiated powers.

Viewers (particularly at the edge of the coverage area) receive their signals with high-gain, directional fixed rooftop antennas of a single polarisation. These are aligned with transmitter stations providing a combination of their correct regional programme and reliable coverage. Once installed it is desirable for viewers and broadcasters alike to avoid any disruption caused by the need to realign these antennas to another station.

Observation 3: Viewer disruption, caused by the need to realign receiving aerials is of significant concern to PSBs.

Multiple high definition (HD) programmes are now routinely delivered over these DTT networks. Some European countries for example, have converted all, or a majority of their DTT services to HD. Suitable capacity should be available to deliver a similar number and quality of services.

Observation 4: HPHT terrestrial broadcast networks routinely deliver multiple HD television services to fixed rooftop reception.

4. Mobility

Another interesting use case for broadcasters is the delivery of audio-visual services to mobile devices with high speed mobility (e.g. up to 250km/hr as set out in the requirements). In line with their existing commitments, seeking near universal geographic coverage of population and roads would be a priority for PSBs, including in urban and rural areas.

Due to the challenging link budget in mobile environments, a performance similar to the capability of existing digital transmission systems should be sought in this environment.

Observation 5: Broadcasting audio-visual services to high speed mobile devices (e.g. 250 km/h) with target spectral efficiencies similar to the capability of existing digital broadcasting systems is an interesting use case for PSBs.

The wide range of audio-visual services that broadcasters deliver calls for the support of different carrier bandwidths including 1.4MHz as they may be sufficient to deliver these services while improving the link budget by reducing thermal noise.

Furthermore, a network topology that includes at least some low power low tower, or cellular network infrastructure (similar to those described in [2]) may be a more appropriate network topology to fulfil the high speed use case.

Observation 6: A range of carrier bandwidths, including 1.4MHz should also be considered for the high speed use case.

Observation 7: A network topology that includes at least some low power low tower, or cellular networks may be most appropriate for delivering the high speed use case.

5. Improvements in Capacity and Reliability

5.1 Improvements in capacity

Studies in [3] point to physical layer overheads in LTE eMBMS Rel-14 in the order of 40%. These are made up of the following main parts:

- 20% of the total symbol period is allocated to the CP;
- Around 10% of the carrier bandwidth is used for guard bands;
- More than 10% of the Resource Elements are used for reference signals; and
- One subframe every 40 subframes is used for synchronisation and signalling (i.e. CAS subframe).

It may be possible to improve capacity and spectral efficiency of the system by reducing overheads in these areas:

- Longer active symbol periods relative to CP;
- Reduction in reference signals density;
- Reduction of the frequency guard bands; and
- Less frequent CAS subframes.

Observation 8: The physical layer overheads in LTE eMBMS Rel-14 are in the order of 40%. Consideration should be given to whether greater capacity could be obtained from reducing these overheads.

In addition, the capacity of the system can be increased by the implementation of multi-antenna (MIMO) techniques with spatial multiplexing which are part of the technical specifications for unicast. In the context of broadcasting applications with receive-only devices, MIMO precoding techniques that do not rely on the specific channel realisations experienced by the users such as open-loop precoding can provide additional performance improvements to the broadcast transmissions.

Observation 9: The use of spatial multiplexing MIMO for LTE eMBMS Rel-14 with open-loop precoding strategies has the potential to increase the system capacity.

5.2 Improvements in reliability

EnTV Studies in Rel-14 [4] [5] [6] investigated the link level performance of the CAS in low power low tower networks with multiple transmitting and receiving antennas. These are not typically found in fixed reception from HPHT networks where transmitting and receiving antennas are of a single polarisation. Ricean single input single output (SISO) channels are more typical of this environment.

Observation 10: The performance of the CAS should be assessed against the HPHT use case in order to ensure that it would adequately support wide area coverage from these networks, particularly with reference to observation 3 above and the long echo delays found in networks with large ISDs.

Physical layer time interleaving is often used in latest generation broadcasting standards, particularly with respect to efficiently improving their performance in the presence of impulse noise and time varying channels. Consideration should be given to whether this technique could also improve the reliability of eMBMS in dedicated broadcasting networks.

Observation 11: Consideration should be given to whether physical layer time interleaving would usefully improve the reliability of eMBMS in dedicated broadcasting networks.

6. Summary

The following observations were made with regard to the broadcast requirements described in TR 38.913 as relevant for Public Service Broadcasters:

Observation 1: Public service broadcasters typically have near-universal coverage requirements

Observation 2: HPHT terrestrial broadcast networks are formed of disparate transmitters with a wide range of characteristics including non-uniform ISDs, transmitter heights and radiated powers.

Observation 3: Viewer disruption, caused by the need to realign receiving aerials is of significant concern to PSBs.

Observation 4: HPHT terrestrial broadcast networks routinely deliver multiple HD television services to fixed rooftop reception.

Observation 5: Broadcasting audio-visual services to high speed mobile devices (e.g. 250 km/h) with target spectral efficiencies similar to the capability of existing digital broadcasting systems is an interesting use case for PSBs.

Observation 6: A range of carrier bandwidths, including 1.4MHz should also be considered for the high speed use case.

Observation 7: A network topology that includes at least some low power low tower, or cellular networks may be most appropriate for delivering the high speed use case.

Observation 8: The physical layer overheads in LTE eMBMS Rel-14 are in the order of 40%. Consideration should be given to whether greater capacity could be obtained from reducing these overheads.

Observation 9: The use of spatial multiplexing MIMO for LTE eMBMS Rel-14 with open-loop precoding strategies has the potential to increase the system capacity.

Observation 10: The performance of the CAS should be assessed against the HPHT use case in order to ensure that it would adequately support wide area coverage from these networks, particularly with reference to observation 3 above and the long echo delays found in networks with large ISDs.

Observation 11: Consideration should be given to whether physical layer time interleaving would usefully improve the reliability of eMBMS in dedicated broadcasting networks.

Proposal: The observations above should be incorporated into scenarios and simulation assumptions that should be developed in order to aid the evaluation of Rel-14 LTE based eMBMS with respect to Public Service Broadcasting.

References

[1]. RP-160675, New WID: eMBMS enhancements for LTE, Ericsson, Qualcomm Inc. Nokia Networks, EBU; 3GPP RAN #71, Goteborg, Sweden, March 2016

[2]. RP-167090; Background Information on Inter-site Distances; BBC; 3GPP RAN #86, Goteborg, Sweden, August 2016.

[3]. D. Vargas and D. Mi, Eds., LTE-Advanced Pro Broadcast Radio Access Network Benchmark, Deliverable D3.1, 5G-PPP 5G-Xcast project, Nov. 2017.

[4]. R1-1610312, Considerations on PBCH coverage enhancement, Nokia, Alcatel-Lucent Shanghai Bell; 3GPP RAN #86-bis, Lisbon, Portugal, October 2016

[5]. R1-1611609, Initial acquisition and system information for eMBMS for 100% MBSFN subframe allocation, Qualcomm Inc; 3GPP RAN #87, Reno, Nevada, USA, November 2016

[6]. R1-1611493, Performance results for cell acquisition subframe, Nokia, Alcatel-Lucent Shanghai Bell; 3GPP RAN #87, Reno, Nevada, USA, November 2016

Acknowledgements

This work was supported in part by the European Commission under the 5G-PPP project Broadcast and Multicast Communication Enablers for the Fifth-Generation of Wireless Systems 5G-XCast (H2020-ICT-2016-2 call, grant number 761498). The views expressed in this contribution are those of the authors and do not necessarily represent the project.

3GPP TSG RAN WG1 Meeting #94-Bis R1-1811588

Chengdu, China 08th - 12th October 2018

Agenda item: **6.2.4.2**

Source: EBU, BBC, IRT

Title: Scenarios and simulation assumptions for the LTE based terrestrial broadcast gap analysis

Document for: Discussion

1. Introduction

A new study item has recently been approved in [1] with the intention to identify any gaps in LTE-eMBMS with respect to the requirements for dedicated terrestrial broadcast networks, and to suggest suitable improvements where necessary.

In this contribution, use cases, values for corresponding simulation parameters and methodologies for eMBMS network simulations are set out for discussion. These are intended to help evaluate the performance of eMBMS in order to identify gaps for which improvements would be beneficial. The scenarios, parameters and methodologies in this document are aimed at fulfilling the 5G requirements for terrestrial broadcast networks and relevant to public service broadcasters as set out in [2].

All the scenarios, simulation parameters and methodology are substantially based on the framework already used in 3GPP as part of the Rel-14 EnTV initiative and set out in [3]. Additional figures, representative of High Power High Tower (HPHT) broadcasting networks have been added, as appropriate, based on [4].

2. Use Cases

Three use cases have been identified for the evaluation of the observations and requirements in [2]:

A. Fixed (rooftop antenna) from a HPHT network
B. Outdoor portable handheld with integrated antenna
C. Mobile outdoor
    a. Car mounted antenna
    b. UE handset docked inside vehicle

It is important that the reception of both the cell acquisition subframe (CAS) and the PMCH should be considered for each use case in order to ensure that the CAS adequately supports the reception of the PMCH i.e. observation 10 of [2].

3. Simulation Parameters for Use Cases A, B and C

The simulation parameters/assumptions below for all three use cases are substantially based on those already used in 3GPP [3].

Additional information on HPHT terrestrial broadcasting networks has been obtained from [4] to serve the Fixed (rooftop antenna) use case. The Inter-site Distance (ISD), Base Station (BS) antenna height, BS antenna gain and BS power for use case A (fixed) have all been derived from table 4 of this reference.

[5] showed that the ISD of real mobile networks is likely to vary between urban and rural environments. It was found that while it is likely that the ISD of real networks in urban areas may be around 2km, 15km is more representative in rural areas. For use cases B and C it is believed that the most challenging

environment will be in rural areas due to the greater ISD. It is therefore considered sufficient to assess the rural case alone i.e. 15km ISD.

Tables 1, 2 & 3 below, appear in [3]. They have been updated for the purposes of this study.

Parameter	Fixed (rooftop antenna)	Outdoor portable (handheld with integrated antenna)	Mobile Car Mounted Antenna	Mobile UE Mounted in Dock
ISD	125km (ITU-R BT.2337-1)	15 km [5]	15 km [5]	15km [5]
Cyclic Prefixes (CP)/Symbol Period	To be determined from the studies	To be determined from the studies	To be determined from the studies	To be determined from the studies
Carrier frequency	700 MHz			
Channel BW	10MHz	1.4, 3, 5, 10MHz	1.4, 3, 5, 10MHz	1.4, 3, 5, 10MHz
BS Power	70 dBm*	46 dBm	46 dBm	46 dBm
BS antenna gain	13 dBi*	15dBi	15dBi	15dBi
BS antenna pattern	Omni-directional. No vertical pattern.			
BS antenna height	300m (ITU-R BT.2337-1)	30m	30m	30m
Unicast control region in MBSFN subframes	None			
Cellular Layout	Hexagonal grid, 61 cell sites, 1 sector per site 1 MBSFN Area (No inter-MBSFN Area interference is modelled)			
Propagation model	ITU 1546	Okumura Hata or ITU 1546		
Signal time probability: Wanted / Interfering	50% / 1% (wanted / interfering)	50% / 1% (wanted / interfering) *If the Okumura-Hata model is used for the propagation model (Table 2), then since interpolation is not required, this signal time probability is no longer needed.*		
EVM	Tx EVM is 8% For these evaluations, these EVM values are independent of the CP numerology.			

Table 3: General Parameters

*Taken together, the BS Power and BS antenna gain are representative of the Effective Isotropic Radiated Power (EIRP) of a high power television tower in [4]

Parameter	Fixed (rooftop antenna) rural	Outdoor portable (handheld with integrated antenna)	Mobile Car Mounted Antenna	Mobile UE Mounted in Dock
Propagation model	ITU-R P.1546-5 Rural	ITU-R P.1546-5 Urban or Okumura-Hata defined in Annex 8 of ITU-R.P1546-5.	ITU-R P.1546-5 Rural or Okumura-Hata defined in Annex 8 of ITU-R.P1546-5.	ITU-R P.1546-5 Rural or Okumura-Hata defined in Annex 8 of ITU-R.P1546-5.
Channel type	TU12 with Rice Factor 10 dB (see Note 1)			

Receiver velocity	0km/h	3km/h	Up to 250km/h [2]	Up to 250km/h [2]
Receiving antenna height (a.g.l.)	10 m	1.5 m	1.5m	1.5m
Height Loss: The difference between the signal level at 10m and the actual receiving antenna height	0 dB	16.5dB (23.5 dB corresponds to urban environment)	16.5dB (23.5 dB corresponds to urban environment)	16.5dB (23.5 dB corresponds to urban environment)
Building penetration loss	n/a (rooftop antenna)	n/a	n/a	8dB Table A1.7 [6]
Location variation / shadowing standard deviation	5.5 dB	5.5 dB	5.5 dB	5.9** dB Table A1.7 [6]
Shadowing correlation	Correlation 1 for sectors of same site; Uncorrelated between sites.			
Man-made noise	0 dB		0dB	0dB

Table 4: Channel Characteristics

Note 1: To simulate the TU12 model with a 10dB Rice Factor, a non-fading zero-delay tap can be added to the already defined Rayleigh fading taps. The power ratio of this non-fading zero-delay tap to the sum of all other TU12 taps is set to 10dB. It is noted that the TU12 itself also has a zero-delay tap, which is kept, but its impact is not that large compared to the added non-fading zero delay tap.

** [6] states that there is a 2dB variation in vehicle penetration loss. 5.9dB incorporates this figure i.e. sqrt(5.5^2+2^2).

Parameter	Fixed (rooftop antenna)	Outdoor portable (handheld with integrated antenna)	Mobile Car Mounted Antenna	Mobile UE Mounted in Dock
Receiver noise figure	6 dB	9 dB	6dB	9dB
Receiver noise bandwidth	9 MHz	1.1, 2.7, 4.5, 9 MHz	1.1, 2.7, 4.5, 9 MHz	1.1, 2.7, 4.5, 9 MHz
Receiver antenna (gain & pattern)	13.15 dBi Discrimination pattern according to ITU-R BT.419-3 band IV, V	-7.35 dBi Non-directional	3.0 dBi Non-directional	-7.35 dBi Non-directional
Antenna Cable Loss	4 dB	0 dB	0dB	0dB
2-Rx Diversity	No	Yes	Yes	Yes
Implementation Margin	1 dB	1 dB	1dB	1 dB
Body loss at receiver	0 dB	2 dB (device is in viewing position)	0dB	0dB
Rx synchronization method	Maximum C/I			
Unicast control region in MBSFN subframes	None			

Channel estimation	Realistic based on proposed RS design
EVM	Rx EVM is 4% For these evaluations, these EVM values are independent of the CP numerology.
ISI/ICI modelling	See section 4 in [3]

Table 5: Receiver Characteristics

4. Receiving Antenna Alignment

For use case A it will be necessary to align the directional, roof-top receiving antenna with a particular base station before the coverage of the network may be assessed. It is therefore important to define the method to be used for this purpose.

Observation 3 in [2] sets out that receiving antenna alignment is of particular interest for broadcasters, particularly for existing networks where it is necessary to avoid viewer disruption through the realignment of receiving antennas that have already been installed. It is therefore believed that studies assuming the most optimal alignment methods may be too optimistic to take this concern into account.

It is therefore proposed that, at each receiving location, the receiving aerial be aligned to the transmitter that provides the strongest signal (or conversely the lowest path loss), on average, before location variation/shadowing is taken into account. In the event of a tie, the direction of alignment may be chosen arbitrary from the strongest transmitters that have been identified. Once the receiving antenna alignment has been determined for a particular location the alignment should remain this way while the statistics for the location are generated. The process is repeated for each location so that always the strongest signal, on average, is selected.

Note that for use cases B and C with omni-directional antennas, this process does not apply.

5. Coverage Definition for Fixed Rooftop in MBSFN Areas

The objective of broadcasting is to provide the same capacity to all users over the entire coverage area for a given reception quality. In hexagonal grid simulations, users are uniformly distributed across the coverage area, implying that the same capacity should be delivered to all locations within it. The capacity available across the entire network may therefore be adequately determined by finding the locations where the minimum capacity occurs.

For the 61site network shown in figure 1, figure 2 provides an example of the percentage of users at each location that would receive a given SINR across the network for the prediction area shown i.e. the coverage quality. The use case is a fixed rooftop scenario with parameters broadly in line with those described in section 3. All sites in the network are in the same MBSFN Area and all sites synchronously transmit the same CAS with the same cell ID and signalling content.

Figure 2-right shows us that the coverage quality varies across the network. In this example it is possible, at some locations, to receive a particular capacity (or SINR) with a certain quality approaching 100% while at others the quality is lower, at around 97%. The minimum capacity can be found at a reception point which lies on a line between the central hexagon and any one of its six apexes. It is therefore sufficient to consider the coverage along a line between these two points, as shown by the dashed line in figure 2-right.

The point with the minimum capacity will be located at different points along this line depending on the parameters of the simulation such as the ISD and CP. Restricting the analysis to locations along this line would represent a significant simplification.

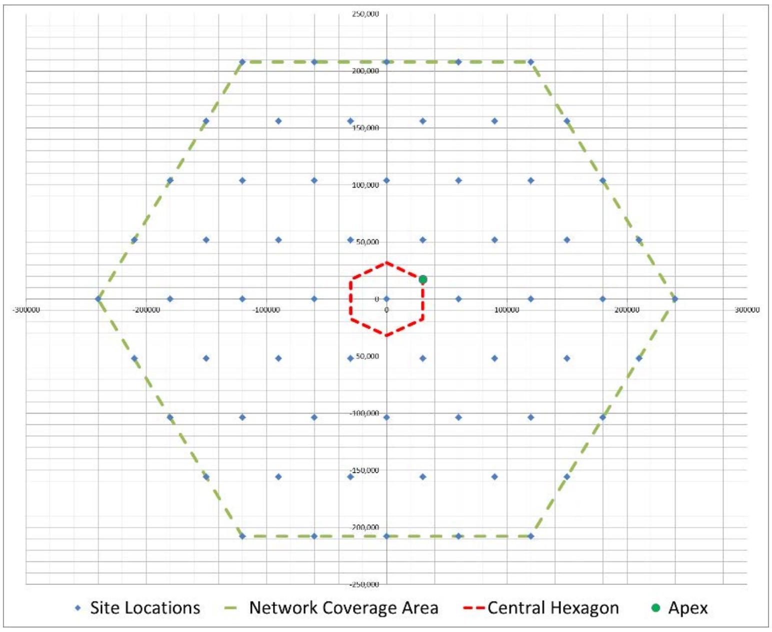


Figure 1: Hexagonal Network

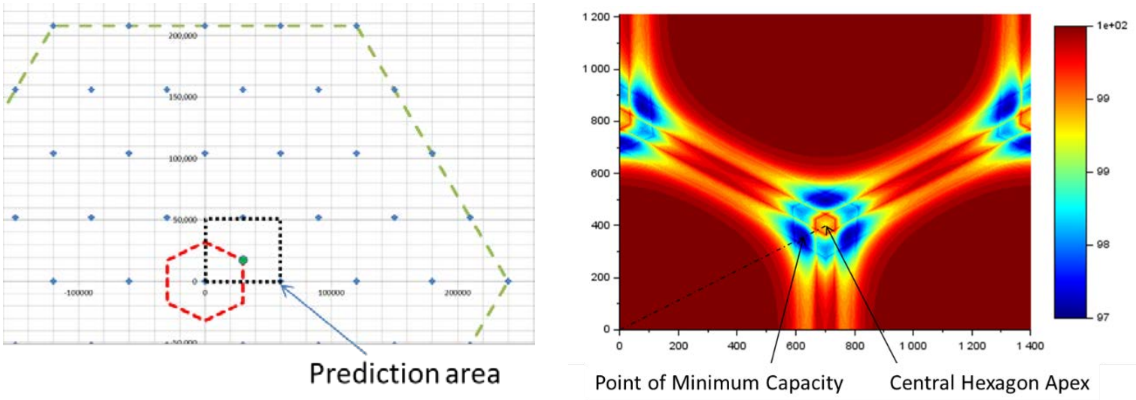


Figure 2: Identifying the minimum capacity in the MBSFN area. Left: Prediction area. Right: Coverage quality within the prediction area.

In order to correctly receive the PMCH it is first necessary to decode the cell acquisition subframe (CAS). The CP of the CAS is limited to the extended unicast numerology (16µs) while the CP of the PMCH may be considerably longer. At some locations within an MBSFN area it is possible that, due to this disparity, the PMCH may be receivable while the CAS would not. The long CP of the PMCH may adequately protect this signal from echoes with long delays from distant transmitters while the CAS may suffer SFN self-interference, rendering it unreceivable. Both signals must be receivable at each location to ensure proper reception. The analysis above should therefore be done simultaneously for both the PMCH and the CAS to ensure that both signals are available at each location with at least the minimum coverage quality.

Such an assessment may be summarised as shown by Figure 3 where the coverage quality of the PMCH and the CAS has been plotted for a large number of points along the ‘worst point line’ of figure 2.

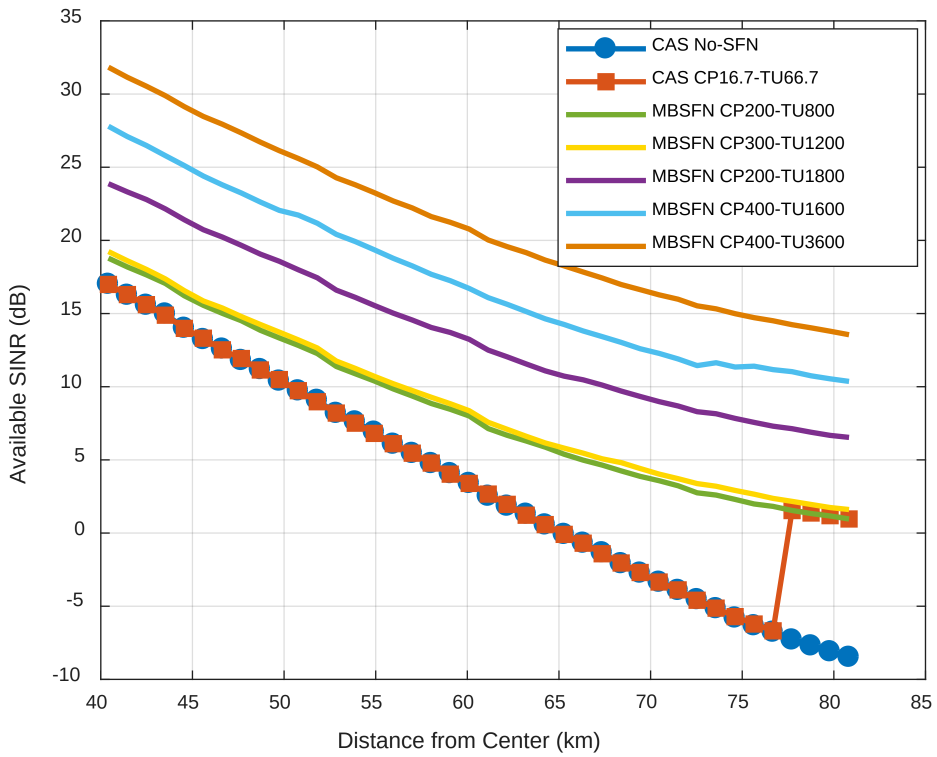


Figure 3: Locating the minimum capacity on the “line of minimum capacity” (from 40 km to 80 km from cell center in a hexagon network of use case A.

6. Methodology Approach

Monte Carlo simulations may be used to estimate the minimum available spectral efficiency in the three use cases described above in clause 2.

A region of interest (RoI) is defined comprising locations in the cell suitable to experience the minimum spectral efficiency i.e. the worst reception point.

For *i*=1:# of points in the RoI

1. Calculate two arrays of values with the field strength of all paths between UE location *j* and the *N* transmitter sites in the network for the ITU-R P.1546 model with 50% time percentage (array_50) and 1% time percentage (array_1).

2. Select the transmitter site with the strongest field strength from array_50 or array_1. This contribution determines the transmitter site toward the receive antenna will point for the simulation (by aligning the 0° towards the site). Note that in case of equal strong paths the selection of the transmitter will be done arbitrarily.

3. Apply the antenna diagram loss to each contribution in array_50 and array_1 according to the relative angular position between the UE location *j*, the selected transmitter site *n* and each of the remaining *N*-1 transmitter sites.

4. Generate *N* uncorrelated arrays of *K* log-normal distributed values with 0 dB mean and 5.5 dB standard deviation.

5. Apply the distribution on top of each of the *N* values in array_50 and array_1. This generates the received field strength for all paths at the receiver antenna input.

6. For each *k*:

a. Select the strongest of the set of *N* values in array_50 or array_1 and calculate the relative delay to the *N*-1 transmitters.

b. Calculate the corresponding *w(t)* for each of the *N* transmitters and apply the value to both array_50 and array_1 as follows:

i. For array_50, apply the value *w(t,n)**array_50

ii. For array_1, apply the value (1-*w(t,n)*)*array_1

c. Calculate the available SINR as sum{ *w(t,n)**array_50}/sum{(1-*w(t,n)*)*array_1 + *N*}

7. Collect the statistics.

The position in the RoI with the minimum SINR (worst point) is chosen as the final value to determine the coverage.

The RoI may be defined with consideration of sections 5 and 6 above.

W(t) is the LTE eMBMS delayed signals weighting function as defined in [7].

7. Performance Metric

The Spectral Efficiency that can be achieved with a 95% coverage probability for fixed reception and 99% for mobile are the key metrics that should be used to assess the performance of the candidate numerologies in the use cases defined.

From the network coverage simulations, CDFs of the SINR of the MBSFN at the worst point can be determined. Using these CDFs, the SINR that is achievable with the appropriate coverage probability can be found.

A suitable lookup table, derived from link level simulations, will be required in order to convert the achievable SINR to MCS and corresponding spectral efficiency.

8. Summary

This document has presented three use cases for consideration when evaluating LTE-eMBMS with respect to dedicated terrestrial broadcast networks. It is suggested that the simulation framework established in [3] is suitable for re-use for these purposes. In line with this suggestion the previously defined simulation parameters have been reviewed and updated for discussion. Additional information has then been provided on a methodology which could be used to align directional receiving antennas in the simulations – agreeing an appropriate methodology for this aspect is an important step in establishing the simulation framework necessary for suitable assessments to be made.

Further background information has also been provided with the intention of performing some of the simulations in an efficient and unambiguous way across all organisations.

9. References

[1]. RP-181706; “Study on LTE-based 5G Terrestrial Broadcast”; Qualcomm Inc.; 3GPP TSG RAN #81, Gold Coast, Australia, September 2018.

[2]. R1-1810319; “Public service broadcaster requirements and background information relevant to LTE-based 5G Terrestrial Broadcast”; EBU, BBC, IRT; 3GPP TSG RAN WG1 Meeting #94-Bis, Chengdu, China, October 2018.

[3]. R1-163939; “Summary of offline discussions on eMBMS simulation considerations”; Nokia, Alcatel-Lucent Shanghai Bell, Ericsson, Fraunhofer IIS, Qualcomm; 3GPP TSG RAN WG1 Meeting #84bis, Busan, Korea, April 2016.

[4]. ITU-R BT.2337-1; “Sharing and compatibility studies between digital terrestrial television broadcasting and terrestrial mobile broadband applications, including IMT, in the frequency band 470-694/698 MHz”; ITU; November 2017.

[5]. R1-167090; “Background Information on Inter-site Distances”; BBC; 3GPP RAN #86, Goteborg, Sweden, August 2016.

[6]. Tech 3348; “Frequency and Network Planning Aspects of DVB-T2, Version 4.1.1”; EBU, October 2014.

[7]. TR 034, “Simulation Parameters for Theoretical LTE eMBMS Network Studies”; EBU; December 2015.

10. Acknowledgements

This work was supported in part by the European Commission under the 5G-PPP project Broadcast and Multicast Communication Enablers for the Fifth-Generation of Wireless Systems 5G-XCast (H2020-ICT-2016-2 call, grant number 761498). The views expressed in this contribution are those of the authors and do not necessarily represent the project.

3GPP TSG RAN WG1 Meeting #95 R1-1812430

Spokane, USA 12th - 16th November 2018

Agenda item: **6.2.4.1**

Source: EBU, BBC, IRT

Title: Evaluation Results for LTE-Based 5G Terrestrial Broadcast

Document for: Discussion

1 Introduction

This document summarises the results of coverage simulations carried out for the Study Item on LTE-Based 5G Terrestrial Broadcast [1] and proposes recommendations to be included for TR36.776. The sub-set of scenarios that appear in this document includes the most relevant scenarios for EBU members.

2 Fixed Rooftop Reception

This section presents the results for the fixed rooftop receiving environment with a directional receiving antenna.

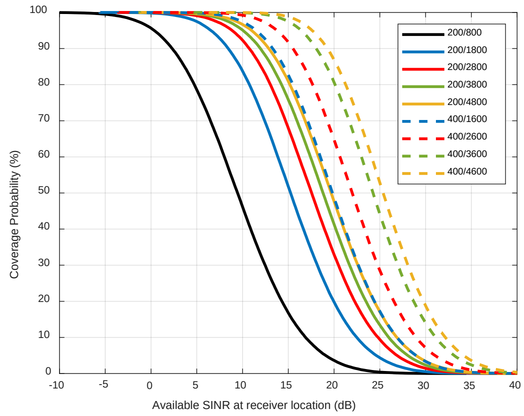
In all cases in this section the receiving antenna has been aligned to the closest transmitter (i.e. the transmitter providing the strongest signal before shadow fading – both fast and slow – has been taken into account). This method has been chosen in recognition that, at each household, it is usually only practical to install antennas in one or two limited locations (see Annex 1 for further background information). Permitting the receiving antenna to be positioned at any location, and while aligning it to the strongest signal, post shadow fading, may therefore be too optimistic.

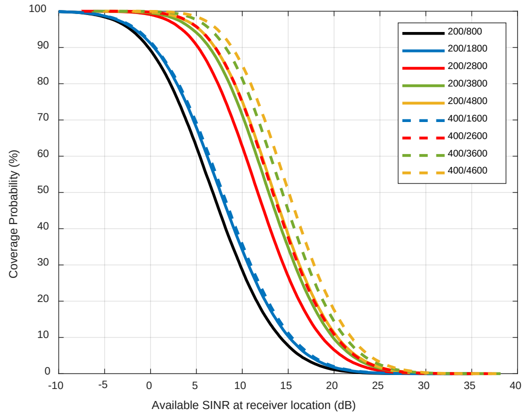
Furthermore, all simulations in this section have been done at the location providing the minimum capacity within the network (i.e. the corner of the central hexagon in the network as described in section 5 of [2]). A Monte-Carlo simulation, taking into account the antenna alignment above, and shadow fading, has been conducted at this location. Performing the calculations at this location ensures that at least the minimum capacity is available throughout the coverage area while accounting for the natural variability of the field strength due to shadow fading. The calculations have been carried out according to the algorithm described in section 6 of [2].

Note that in all cases omni-directional horizontal and vertical antenna patterns have been used, with one sector per site. Only one antenna has been used at the BS and UE. Fast-fading and UE speed has not been considered – their effects should be taken into account as a result of link-level simulations.

All other parameters are aligned with [3] and any subsequent agreements.

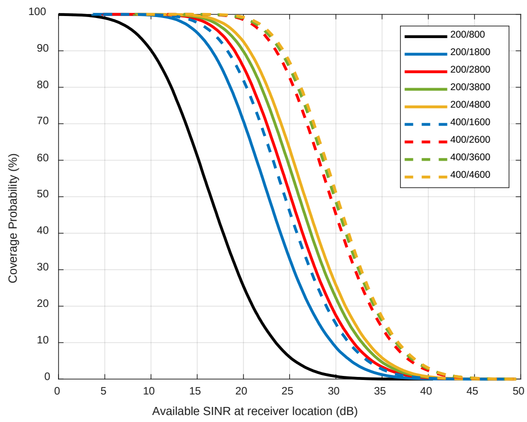
The simulation results appear in the plots below where each curve represents a specific numerology with the CP/T_u fraction shown. Only the 200/800 (ie 800µs T_u, 200 µs CP) numerology has been standardised – the other numerologies have been hypothesised in order to show the benefit of increasing the CP and/or T_u. In all cases the reference signal pattern of the existing 200 µs CP numerology has been assumed. Under this assumption, increasing T_u similarly increases the equalisation interval (EI) - the interval over which echoes with long delays may be correctly equalised. As the results show, increasing T_u may significantly increase a network's capacity.

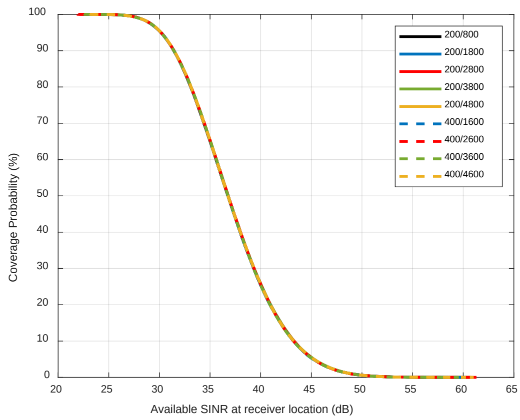




a) HPHT1

b) HPHT2





c) MPMT

d) LPLT

Figure 1: SINR vs Coverage Probability at the location of minimum capacity for the network configurations shown. Fixed rooftop reception.

The SINR achieved for 95% locations is summarised in the Table 1.

CP/ T_u (μs)	200/ 800	200/ 1800	200/ 2800	200/ 3800	200/ 4800	400/ 1600	400/ 2600	400/ 3600	400/ 4600
HPHT1	0.35	6.55	8.86	10.06	10.99	11.52	13.76	16.42	17.6
HPHT2	-2.19	-1.71	3.42	4.57	5.32	-1.53	5.35	6.5	7.28
MPMT	8.29	14.98	17.44	18.35	19.12	16.6	22.05	22.5	22.85
LPLT	30.15	30.15	30.15	30.15	30.15	30.15	30.15	30.15	30.15

Table 1: Achievable SINR (dB) at 95% locations. Fixed rooftop reception.

Table 1 shows that, for HPHT1 and HPT2, increasing the CP to 400 μs would significantly increase the achievable SINR compared with the existing 200 μs CP. It can also be seen that simultaneously increasing the useful symbol duration (T_u) up to 4,600 μs would be similarly beneficial. The same trend is evident for MPMT, although the benefit of increasing T_u beyond 2,600 μs is less pronounced. For LPLT there is no benefit in increasing the CP or T_u beyond 200 μs and 800 μs respectively.

Increasing T_u and/or the CP in the manner set out above would involve narrower carrier spacings (as shown in table 2). Inevitably this would have implications for the system's Doppler performance. Evidence suggests, however, that narrower eMBMS carrier spacings may be possible. In the case of fixed rooftop reception, carrier spacings of 280 Hz have been shown to perform adequately well in the field – Digital TV services have now been successfully delivered with this carrier spacing for a number of years [4]. Considering carrier spacings in this order for eMBMS may therefore be worthwhile.

Furthermore, increasing T_u in order to reduce LTE's conventional Cp/(T_u + CP) ratio of 20% would also reduce the overhead given over to the CP, as Table 2 shows. For fixed rooftop reception, numerologies with a carrier spacing in the order of 280 Hz may be of particular interest.

CP/ T_u (μs)	200/ 800	200/ 1800	200/ 2800	200/ 3800	200/ 4800	400/ 1600	400/ 2600	400/ 3600	400/ 4600
Carrier Spacing (Hz)	1250	556	357	263	208	625	385	278	217
CP/(T_u + CP) Overhead	20%	10%	6.7%	5%	4%	20%	13.3%	10%	8%

Table 2: Carrier spacings and CP overhead for numerologies used in simulations

Table 2 shows the carrier spacings for the enumerations in table 1. The carrier spacing of the 400/3600 μs CP/ T_u option would be closely aligned with 280 Hz and would be a good option to consider.

Observation 1: For fixed rooftop reception from networks with large ISDs, increasing the CP duration to 400 μs would significantly increase the achievable SINR, and therefore the capacity, of such networks relative to the current maximum CP of 200 μs.

Observation 2: Real world deployments have established that carrier spacings of around 280 Hz provide adequate Doppler performance for fixed rooftop reception (in the UHF band).

Observation 3: Increasing the duration of T_u for a given CP (i.e. reducing the CP/T_u fraction), would further improve the achievable SINR in HPHT and MPMT networks, and therefore capacity, through a longer equalisation interval.

Recommendation 1: A longer CP of 400μs should be standardised to cover large geographical areas from real-world networks with large ISDs

Recommendation 2: Consideration should also be given to reducing the CP/T_u fraction as this would increase the achievable SINR while further reducing overheads. Numerologies with carrier spacings in the order of 280 Hz may be most appropriate due to Doppler performance.

3 Mobile Reception – Car Mounted

This section presents the results for the mobile reception environment with an omni-directional receiving antenna. The methodology used in section 2 has also been applied here, with the exception that due to the receiving antenna being omni-directional there is no need to align the receiving antenna to any particular site. The results are shown for the car mounted reception scenario within a rural environment.

Note that in all cases omni-directional horizontal and vertical antenna patterns have been used, with one sector per site. Only one antenna has been used at the BS and UE. Fast-fading and UE speed has not been considered – their effects should be taken into account as a result of link-level simulations.

All other parameters are aligned with [3] and any subsequent agreements.

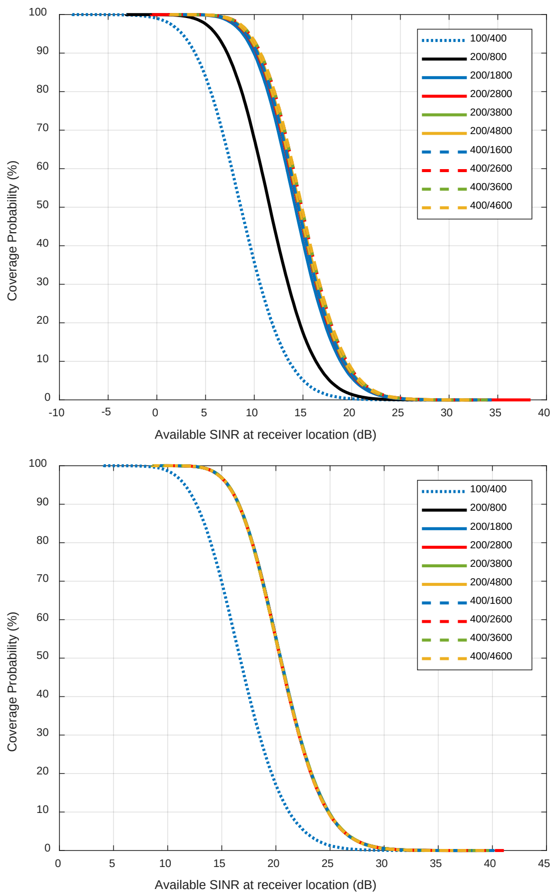


Figure 2: SINR vs Coverage Probability at the Location of Minimum Capacity for car mounted reception. MPMT (left), LPLT (right).

The SINR achieved for 95% locations is summarised in the Table 2.

CP/ T_u (µs)	100/ 400	200/ 800	200/ 1800	200/ 2800	200/ 3800	200/ 4800	400/ 1600	400/ 2600	400/ 3600	400/ 4600
MPMT	2.1	6.0	8.8	9.2	9.2	9.3	9.2	9.5	9.5	9.5
LPLT	11.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6

Table 3: Achievable SINR (dB) at 95% locations. Car mounted reception.

Table 3 shows that there may be some merit in introducing an additional numerology for the 200 µs CP with a longer T_u (e.g. 1800 or 2800 µs) in order to improve the capacity in this reception mode for MPMT networks. However, the Doppler performance of such a numerology would have to be carefully considered.

The table also shows that there would be no benefit in increasing the CP or the T_u for this reception mode from LPLT networks. Furthermore, shortening the CP would reduce the achievable SINR – it would degrade from 15.6 dB to 11.6 dB.

However, the degradation is tolerable as a usefully high SINR would still be achievable. Most importantly, the 100µs would improve the Doppler performance of the system by approximately a factor of two relative to the existing 200µs numerology. Thus the shorter, 100µs CP would be a good compromise between Doppler performance and coverage for LPLT networks.

Observation 4: LPLT networks appear to be best suited for delivering services to car mounted reception.

Observation 5: A CP of 100 µs would be a good compromise between Doppler performance and coverage for the LPLT car mounted reception use case.

Recommendation 3: A CP of 100 µs should be standardised in order to improve mobility in LPLT networks.

4. CAS

In order to correctly receive the PMCH it is first necessary to decode the cell acquisition subframe (CAS). The CP of the CAS is limited to the extended unicast numerology (16.67 µs) while the CP of the PMCH may be considerably longer. Due to this disparity, at some locations within an MBSFN area it may not be possible to receive the CAS while it would otherwise be possible to receive the PMCH. The long CP of the PMCH may adequately protect the PMCH signal from long delayed echoes while the CAS may suffer SFN self-interference, rendering it unreceivable. Both signals must be decodable at each location to ensure proper reception.

The different numerologies used by the PMCH and the CAS may cause the minimum achievable SINR locations for each signal to occur in different places. However, due to the symmetry of the network under consideration the minimum SINR locations for both signals may be found on a line drawn between the central transmitter and any one of the six corners of the central hexagon (i.e. the minimum capacity line), as described in section 5 of [2].

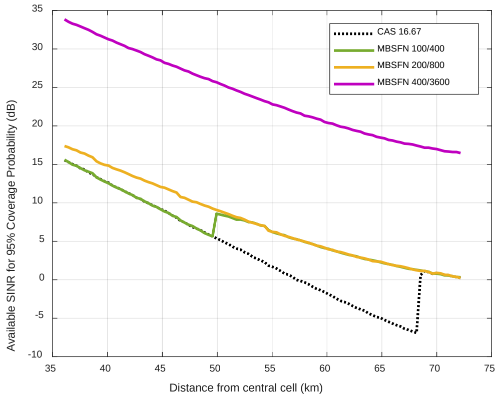
In this section we plot the SINR for the CAS and the PMCH on the minimum capacity line re-using the methodology described in sections 2 and 3 as appropriate.

Note that in all cases omni-directional horizontal and vertical antenna patterns have been used, with one sector per site. Only one antenna has been used at the BS and UE. Fast-fading and UE speed has not been considered – their effects should be taken into account as a result of link-level simulations.

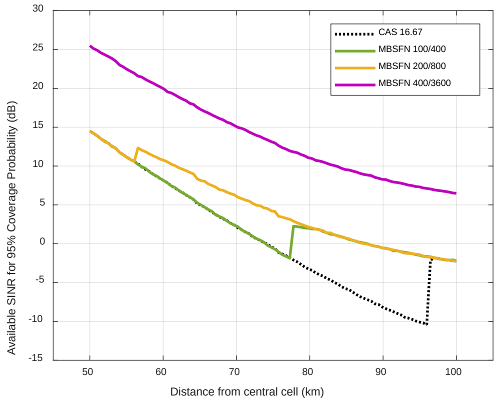
All other parameters are aligned with [3] and any subsequent agreements.

We assume the CAS would be synchronised at every site and carrying the same content so that it too could form a synchronised SFN with the 16.67µs CP.

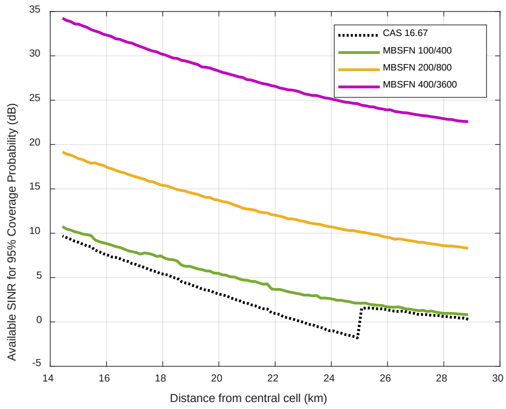
The results show that in all cases the CAS is the limiting factor for correct reception – the achievable SINR for the CAS falls below that of the PMCH in the graphs below. The step changes in the CAS (and other) curves appears as the reception location moves into or out of the region protected from MBSFN self-interference by the equalisation interval and/or CP i.e. the SFN weighting curve described in [5].

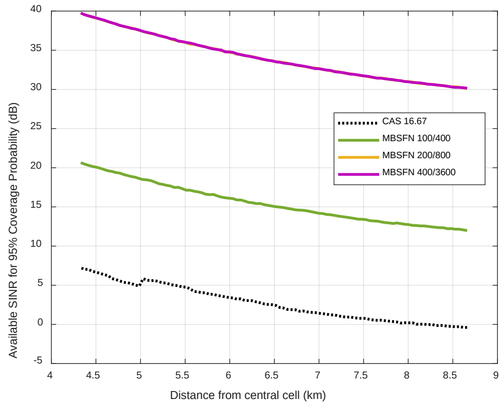


a) HPHT1



b) HPHT2

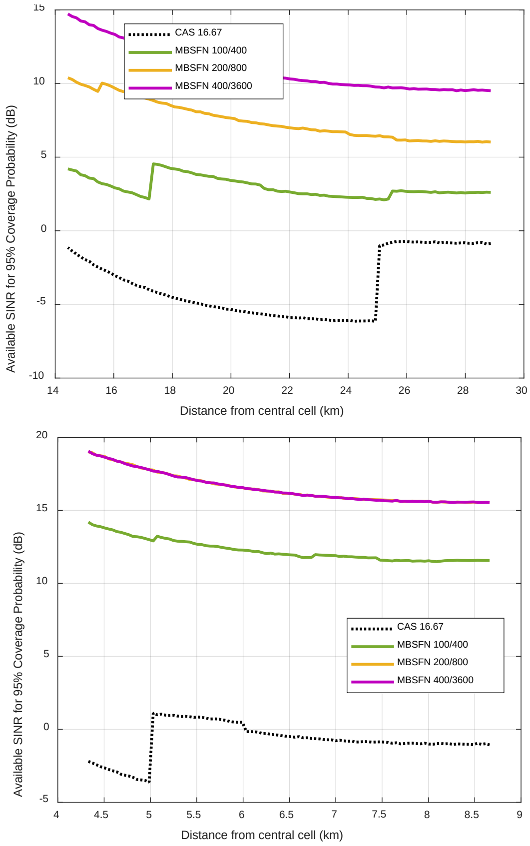




c) MPMT

d) LPLT

Figure 3: Achievable SINR for the CAS and the PMCH along the line of minimum capacity for the network configurations shown. Fixed rooftop reception.



a) MPMT

b) LPLT

Figure 4: Achievable SINR for the CAS and the PMCH along the line of minimum capacity for the network configurations shown. Car mounted reception.

The minimum SINR achieved by the CAS for the network topologies above is summarised in Table 4. The two most onerous cases are HPHT1 and HPT2 where the CAS would need to be receivable with an SINR of circa -6.9 to -10.4 dB respectively. The MPMT network would, for car mounted reception, would require an SINR of circa -6.1dB.

	Limiting SINR of the CAS 16.67 µs CP Fixed Rooftop	Limiting SINR of the CAS 16.67 µs CP Car Mounted
HPHT1	-6.9 dB	-
HPHT2	-10.4 dB	-
MPMT	-1.8 dB	-6.1 dB
LPLT	-0.4 dB	-3.6 dB

Table 4: Achievable SINR at 95% locations for the CAS.

Observation 6: In order to ensure adequate reception of the PMCH, the CAS should be decodable in both fixed rooftop and mobile environments at SINR levels in the order of -10 to -7dB in the appropriate channels.

Recommendation 4: Link level simulations are required in order to confirm that the CAS would reliably operate in the region of -10 dB to -7 dB SINR in transmission channels appropriate for fixed rooftop reception (i.e. SISO Ricean channels).

Recommendation 5: Link level simulations are required in order to confirm that the CAS would reliably operate in the region of -6 dB to -4 dB SINR in transmission channels appropriate for car mounted channels (i.e. SIMO and MIMO, mobile channels).

6. Summary

Based on the simulations in this document the following observations have been made:

Observation 1: For fixed rooftop reception from networks with large ISDs, increasing the CP duration to 400 µs would significantly increase the achievable SINR, and therefore the capacity, of such networks relative to the current maximum CP of 200 µs.

Observation 2: Real world deployments have established that carrier spacings of around 280 Hz provide adequate Doppler performance for fixed rooftop reception (in the UHF band).

Observation 3: Increasing the duration of T_u for a given CP (i.e. reducing the CP/T_u fraction), would further improve the achievable SINR in HPHT and MPMT networks, and therefore capacity, through a longer equalisation interval.

Observation 4: LPLT networks appear to be best suited for delivering services to car mounted reception.

Observation 5: A CP of 100 µs would be a good compromise between Doppler performance and coverage for the LPLT car mounted reception use case.

Observation 6: In order to ensure adequate reception of the PMCH, the CAS should be decodable in both fixed rooftop and mobile environments at SINR levels in the order of -10 to -7dB in the appropriate channels.

The observations above lead to the following recommendations:

Recommendation 1: A longer CP of 400µs should be standardised to cover large geographical areas from real-world networks with large ISDs

Recommendation 2: Consideration should also be given to reducing the CP/T_u fraction as this would increase the achievable SINR while further reducing overheads. Numerologies with carrier spacings in the order of 280 Hz may be most appropriate due to Doppler performance.

Recommendation 3: A CP of 100 µs should be standardised in order to improve mobility in LPLT networks.

Recommendation 4: Link level simulations are required in order to confirm that the CAS would reliably operate in the region of -10 dB to -7 dB SINR in transmission channels appropriate for fixed rooftop reception (i.e. SISO Ricean channels).

Recommendation 5: Link level simulations are required in order to confirm that the CAS would reliably operate in the region of -6 dB to -4 dB SINR in transmission channels appropriate for car mounted channels (i.e. SIMO and MIMO, mobile channels).

References

[1]. RP-181706; "Study on LTE-based 5G Terrestrial Broadcast"; Qualcomm Inc.; 3GPP TSG RAN #81, Gold Coast, Australia, September 2018.

[2]. R1-1811588, Scenarios and simulation assumptions for the LTE based terrestrial broadcast gap analysis, EBU, BBC, IRT; 3GPP RAN WG1 #94-Bis, Chengdu, China, October 2018

[3]. R1-1811728, Chairman's notes of AI 6.2.4 Study on LTE-based 5G Terrestrial Broadcast, Ad-Hoc chair (Ericsson), 3GPP RAN WG1 #94-Bis, Chengdu, China, October 2018

[4]. Reference Parameters for Digital Terrestrial Television Transmissions in the United Kingdom, Ofcom, November 2016

[5]. TR 034, "Simulation Parameters for Theoretical LTE eMBMS Network Studies"; EBU; December 2015.

Acknowledgements

This work was supported in part by the European Commission under the 5G-PPP project Broadcast and Multicast Communication Enablers for the Fifth-Generation of Wireless Systems 5G-XCast (H2020-ICT-2016-2 call, grant number 761498). The views expressed in this contribution are those of the authors and do not necessarily represent the project.

Annex 1

Due to entirely practical reasons there are commonly severe restrictions on where receiving antennas, mounted at rooftop level, may be located. As the photos below of UK antenna installations show, often the only practical mounting point is the chimney stack. Simple mounting brackets allow receiving antennas to be positioned above the apex of a roof in order to receive a suitably strong signal, clear of local obstructions. In some instances, multiple antennas from different dwellings have to be mounted on the same chimney (figures 1b and 2b). It is far less practical, particularly in terraced housing, to mount the antennas elsewhere (figures 2a and 2b).

Given practical restrictions such as these it may be too optimistic to assume that it is possible, at each location, to align the receiving antenna with the strongest possible signal (e.g. after path loss and location shadowing has been taken into account). The receiving antenna is therefore assumed to be aligned to the closest transmitter, i.e. the transmitter providing the highest signal level before shadow fading has been taken into account.

Figure 1a

Figure 1b

Figure 2a

Figure 2b

3GPP TSG RAN WG1 Meeting #96 R1- 1903284

Athens, Greece 25th February – 1st March 2019

Agenda item: **6.2.4.1**

Source: EBU, BBC, IRT

Title: Evaluation Results for LTE-Based 5G Terrestrial Broadcast

Document for: Discussion

1. Introduction

This document provides additional background information for the Study Item on LTE-Based 5G Terrestrial Broadcast [1]. It summarises the results of network and link level simulations carried out for a number of hypothetical numerologies covering a range of CPs and symbol periods. The results may be used to inform the design of potential new numerologies that would better support the use cases set out in [2]. The sub-set of scenarios that appear in this document includes the most relevant use cases for EBU members.

2. Background

2.1 Naming Convention

The naming convention of CP/T_u[/EI] has been used throughout this document to denote the durations of the cyclic prefix, useful symbol period and equalisation interval of the numerologies investigated below. D_f has also been used to represent the reference symbol (RS) tone separation in the frequency direction and D_t to represent RS separation in the time direction. 200/800/267 with $D_f = 3$ and $D_t = 2$ therefore describes the 200µs CP variant of Rel-14. This mode, like all others in this document is assumed to have an EI of T_u/D_f when time then frequency interpolation of the RS is assumed. For the 200µs CP variant of Rel-14 the EI is 800/3 = 267 µs. D_f and D_t have been defined according to the conventions in [3]

2.2 Simulation Parameters

The simulations have been carried out in a small area at the apex of the central hexagon, as described in section 5 of [4]. The 50/1 (wanted/interferer) time model has been used. Perfect EVM has also been assumed as it may be considered to be a matter of implementation, particularly in the case of HPHT transmitters. The receiving antenna, for fixed rooftop reception, has been aligned to the strongest transmitter before location variation has been applied (also equivalent to the closest transmitter). All other parameters are aligned with [2].

3. Fixed Rooftop Reception

3.1 Numerologies

Network simulations have been carried out for various hypothetical combinations of cyclic prefix (CP), useful symbol period (T_u) and equalisation interval (EI) in order to better understand whether it would be worthwhile defining new eMBMS numerologies for the networks and receiving environments set out in [2]. Table 1 sets out the numerologies used in the network simulations in this section, their inter-carrier spacings (ICS) and their CP overheads.

Numerology Designator	200/ 800	200/ 1800	200/ 2800	200/ 3800	200/ 4800	300/ 1700	300/ 2700	300/ 3700	300/ 4700	400/ 1600	400/ 2600	400/ 3600	400/ 4600
ICS (Hz)	1250	556	357	263	208	588	370	270	213	625	385	278	217
CP/(T_u+CP)	20%	10%	6.7%	5%	4%	15%	10%	7.5%	8.1%	20%	13.3%	10%	8%

Table 1: Numerologies investigated

For each of the numerologies above, a number of different pilot patterns have been investigated with $D_f \in (2, 3, 4, 6, 8)$ and $D_t \in (14, 7, 4, 3, 2)$.

All of the hypothetical numerologies above have narrower ICS than the 1.25 kHz ICS of the release 14 variant. Section 5 indicates that, based on long standing deployments of other OFDM broadcasting technologies, all of the ICS in table 1 are likely to be adequately wide for fixed rooftop reception.

3.2 LPLT

The absolute SINR achieved for the 95% percentile of locations is summarised in figure 1. It is immediately clear that increasing the CP and/or T_u over Rel-14 would provide no SINR improvement in this network/reception environment combination – the 200µs CP of Rel-14 is already long enough to cover the echo delay profile for the LPLT network.

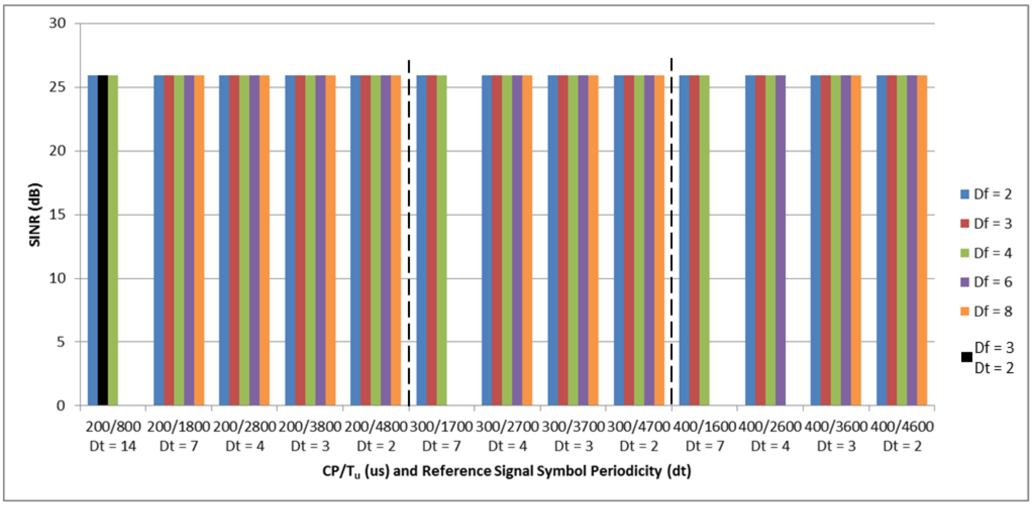


Figure 1: 95th percentile SINR for various numerologies. LPLT fixed rooftop.

Observation 1: Increasing the CP relative to Rel-14 would not improve the achievable SINR in the LPLT network.

Ideally, new numerologies should, however, be designed in order to maximise the spectral efficiency (SE) of a network, rather than the SINR in isolation. Below we attempt to show why this may be the case. In the absence of detailed link level simulations, we have used the unconstrained Shannon capacity (based on the achievable SINR from the simulations) in conjunction with the RS and CP overheads in order to represent the SE of each of the numerologies investigated. i.e.:

$$SE = \log_2(1+SINR_{linear}) * (1-1/D_f D_t) * (1-CP_{overhead})$$

Figure 2 shows the SE relative to the 200us CP numerology of Rel-14. Even though the SINR is constant across all the numerologies, the SE, after incorporating the CP and RS overheads, varies. This is simply because the CP and RS overheads are different from one numerology to another. They should therefore be taken into account. We can see from figure 2 that there would be a number of ways to increase the capacity over Rel-14, the optimal of which would appear to be to increase T_u, This would reduce the CP overhead. Consideration of the RS pattern may also be worthwhile.

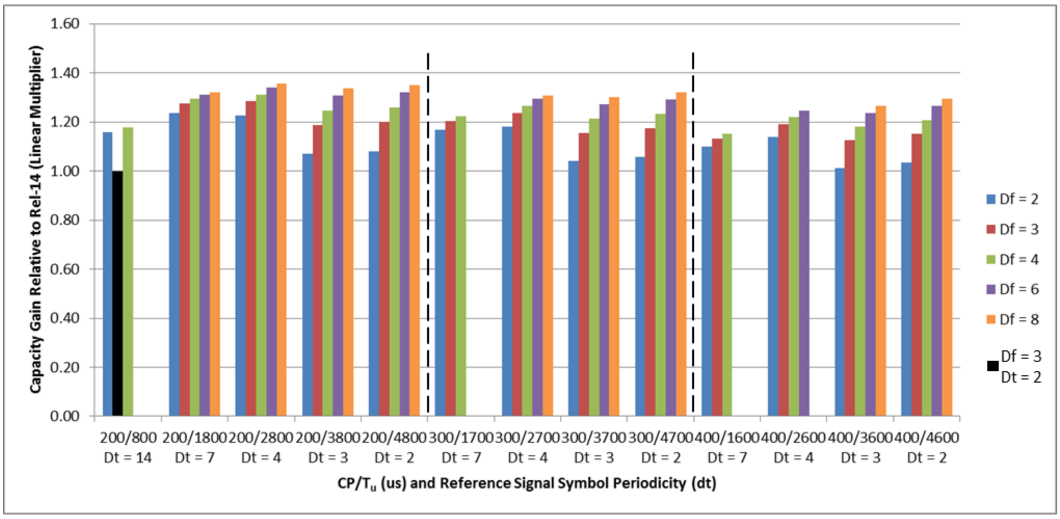


Figure 2: Spectral efficiency of various numerologies. LPLT fixed rooftop.

Observation 2: Increasing T_u in order to decrease the CP overhead relative to Rel-14 would improve the SE in the LPLT network.

Observation 3: Increasing the CP and T_u to 400µs and 4600µs respectively would, although not maximal, provide a significant SE boost in the LPLT network.

Observation 4: Consideration of the RS pattern would also be worthwhile.

3.3 MPMT

The absolute SINR achieved for the 95% percentile of locations is plotted in figure 3. It shows that increasing the CP and/or T_u over Rel-14 would improve the achievable SINR for the MPMT use case. We can see that the achievable SINR keeps increasing as the T_u and CP are extended, with the longest T_u and CP options providing the highest SINR.

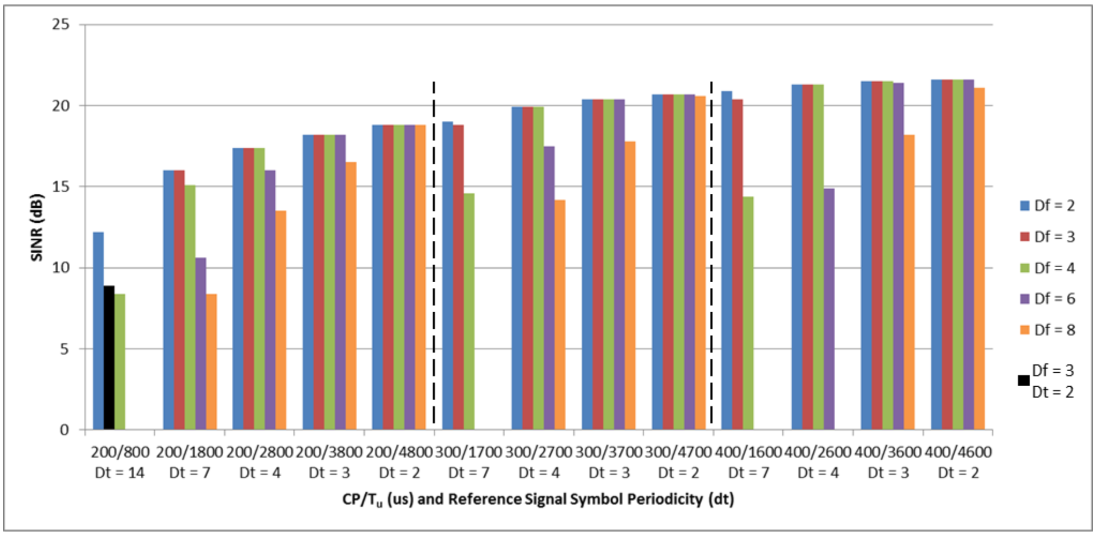


Figure 3: 95th percentile SINR for various numerologies. MPMT fixed rooftop.

Observation 5: Increasing the CP to ≥300µs would significantly improve the SINR relative to Rel-14 in the MPMT network.

The unconstrained Shannon spectral efficiencies are shown in figure 4. Numerologies with CPs of at least 300 µs in conjunction with total symbol periods (T_u+CP) of 3 ms or longer would be most beneficial.

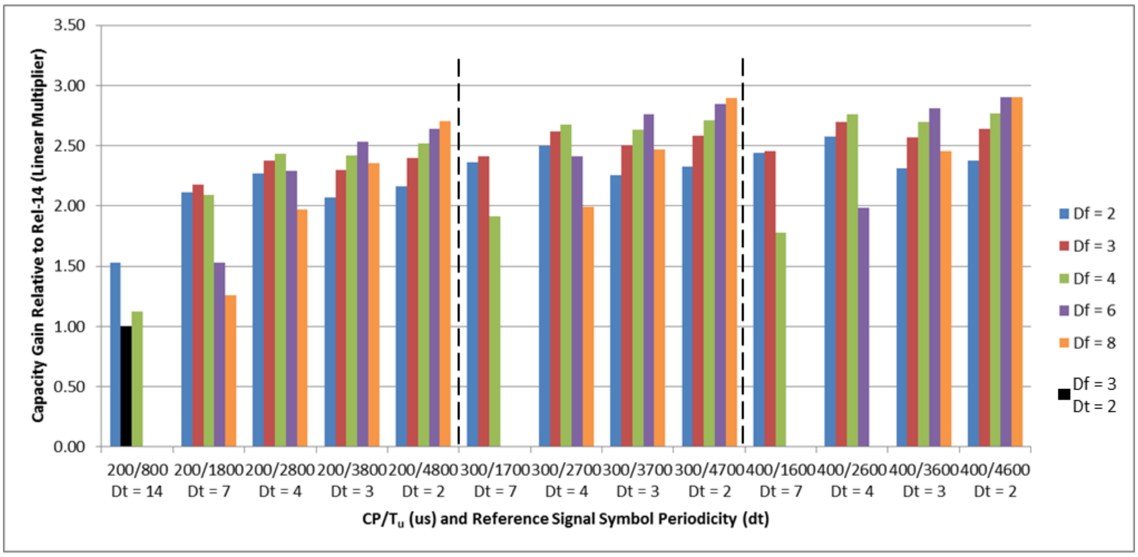


Figure 4: Spectral efficiency of various numerologies. MPMT fixed rooftop.

Observation 6: Increasing the CP to ≥ 300 µs and T_u to ≥ 2600 µs would significantly improve the achievable SINR and SE in the MPMT network relative to Rel-14.

3.4 HPHT1

The absolute SINR achieved for 95% locations in the HPHT network is summarised by figure 5. In this case it can be seen that extending both the CP and T_u would improve the achievable SINR. The longest CP/T_u variants provide the highest SINR e.g. 400 µs CP, 4,600µs T_u.

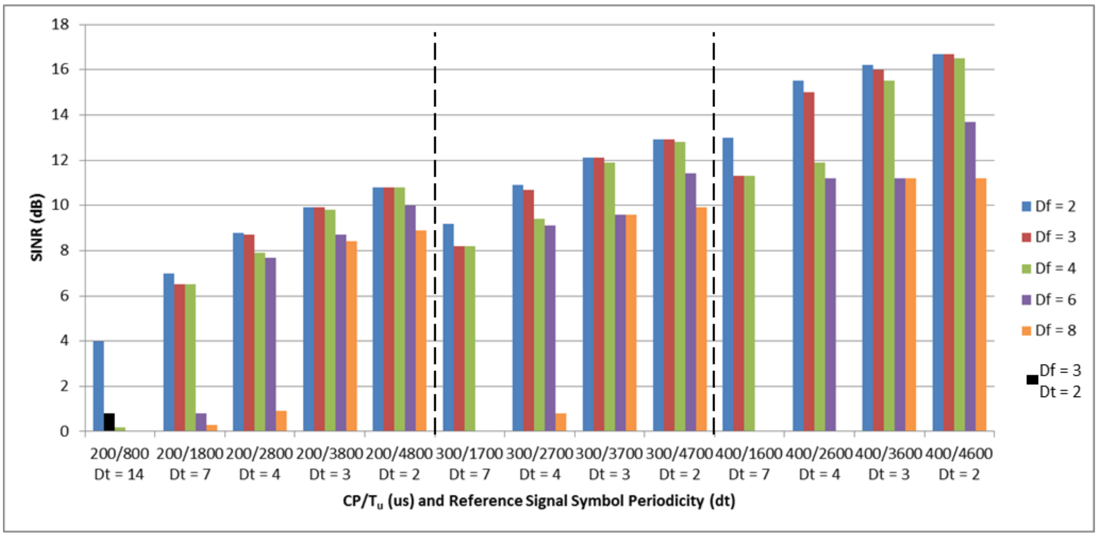


Figure 5: 95th percentile SINR for various numerologies. HPHT1 fixed rooftop.

Observation 7: Increasing the CP to ≥400 µs and T_u to ≥2600 µs would significantly improve the SINR relative to Rel-14 in the HPHT1 network.

Figure 6 shows the unconstrained Shannon spectral efficiency where it can be seen that a 400 µs CP 4600 µs T_u variant would provide the highest SE.

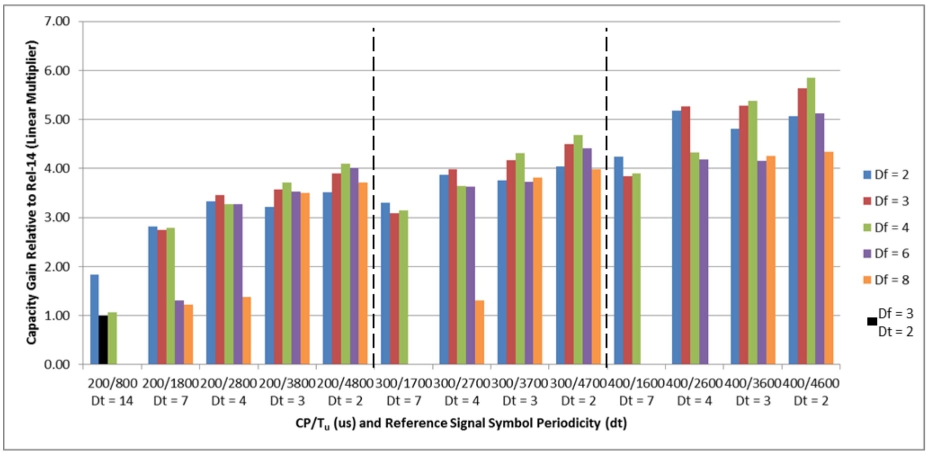


Figure 6: Spectral efficiency of various numerologies. HPHT1 fixed rooftop.

Observation 8: Increasing the CP to 400µs and T_u to 4.6 ms or more would provide the greatest spectral efficiency for the HPHT1 network.

3.5 Summary

For simplicity the observations above have been summarised in table 2. It would appear to be worthwhile investigating longer symbol periods, in the order of 2.6 ms or more, and CPs of 300 µs or more. Careful consideration would need to be given to the design of the RS pattern. Potential new modes should be investigated with respect to SE gains, rather than SINR improvements in the respective networks.

Network	CP	T_u
LPLT	200 µs	> 0.8 ms
MPMT	≥ 300 µs	≥ 2.6 ms
HPHT1	≥ 400 µs	≥ 2.6 ms

Table 2: Guidance for the CP and T_u of new numerologies for fixed rooftop reception

4. Mobile Reception – Car Mounted

This section presents the results for the mobile reception environment with an omni-directional receiving antenna. The methodology of section 2 has also been applied here, with the exception that due to the receiving antenna being omni-directional there is no need to align the receiving antenna to any particular site. The results are shown for the car mounted reception scenario in a rural environment.

4.1 Numerologies

Network simulations have been carried out considering suitable numerologies for high speed scenarios. Therefore, the parameters CP and T_u have been deliberately chosen to provide a good balance between resilience to Doppler spread and coverage in MBSFN. Different values of EI have also been considered as this parameter influences coverage and is dependent on the reference signals, both of which would benefit from careful design. Table 3 sets out the numerologies used in the simulations, their inter-carrier spacings (ICS) and their CP overheads, the latter has been kept to 20% to maximize sub-carrier spacing.

Numerology Designator	**16.7/ 66.7/ 59.4**	**33.3/ 133.3/ 59.4**	**100/ 400/ 178**	**100/ 400/ 119**	**200/ 800/ 356**	**200/ 800/ 238**
ICS (kHz)	15	7.5	2.5	2.5	1.25	1.25
CP/(T_u+CP)	20%	20%	20%	20%	20%	20%

Table 3: Numerologies investigated

The evaluated numerologies have an ICS between the 1.25 kHz ICS of the release 14 variant and the 15 kHz suitable for a single-cell deployment. The car mounted scenario with LPLT network topology has been used as it is well suited to such modes.

4.2 Network Simulation for LPLT

The complementary CDF of the absolute SINR achieved as a function of location is plotted in figure 7. It shows that a 100 µs CP would provide a worthwhile SINR increase over the existing 16.6 and 33.3 µs numerologies in the LPLT network. Although the 200 µs CP variant of Rel-14 would provide a higher SINR, the ICS may be too narrow for high speed reception. The 100 µs CP would be a good compromise between MBSFN coverage and mobility. We can also see that different EI lengths – a factor set in part by the reference signal patterns – would also have an appreciable effect on the SINR. Careful consideration should therefore be given to the reference signal design for any new numerologies, particularly for the mobile case.

The SE of these numerologies should be investigated during the ensuing Work Item.

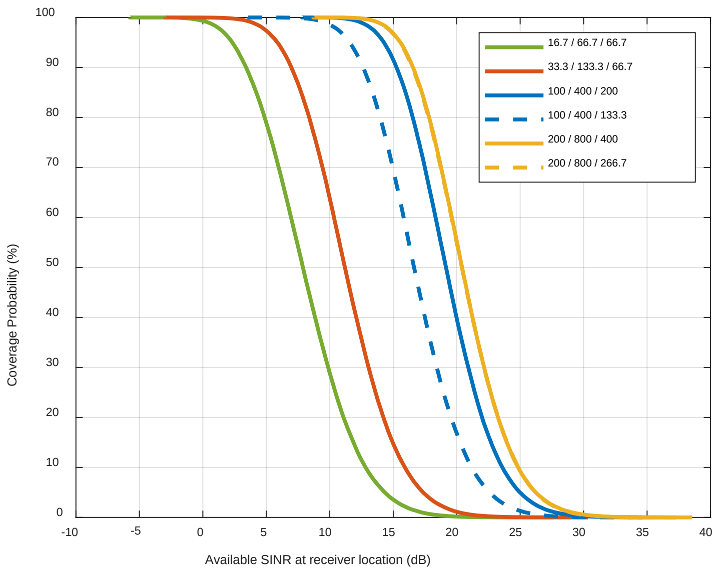


Figure 7: 95th percentile SINR for various numerologies. MPMT car mounted.

Numerology Designator	**16.67/ 66.7/ 66.7**	**33.33/ 133.3/ 66.7**	**100/ 400/ 200**	**100/ 400/ 133**	**200/ 800/ 400**	**200/ 800/ 266.7**
SINR (dB)	2.32	5.87	14.27	11.56	15.57	15.52

Table 4: 95th percentile SINR for various numerologies. MPMT car mounted.

Observation 9: LPLT networks appear to be well suited for delivering services to car mounted reception.

Observation 10: A CP of 100 µs would be a good compromise between Doppler performance and coverage for the LPLT car mounted reception use case.

4.3 Link Level Simulations for LPLT

4.3.1 Simultion Model and Assumptions

The main simulation assumptions for LLS for this Study Item are detailed in TR 36776 v0.0.4. A summary of the most relevant parameters of this contribution are detailed in Table 5.

Parameter	Value
System Bandwidth	10 MHz
Carrier Frequency	700 MHz
Physical Channel	PMCH
Considered Numerologies: CP/subcarrier spacing/FFT size	33.3µs/7.5kHz/2048, 100µs/2.5kHz/6144, and 200µs/1.25kHz/12288
Considered Speeds	60 km/h, 120 km/h and 250 km/h
Reference Signal Pattern for the considered numerologies	For the baseline Rel-14 numerologies (i.e. 33.3µs and 200µs) existing RS pattern. For 100µs CP numerology, staggered RS pattern with one RS every 4 subcarriers and RS every slot (D_f = 2, D_t = 2).
Channel Estimation at Rx	One-dimensional linear interpolation in time and frequency domains
Channel Model	TDL-B with a DS of 20µs and no correlation between receive antennas
Number of Tx at Base Station	1
Number of Rx antennas at UE	2
MCS	6
Transport Block Size	9912 bits
Demodulation Algorithm	Maximum likelihood
Turbo Decoding Algorithm	Max-Log-MAP with a maximum of 8 iterations
Number of stored subframes at UE for channel estimation	1 for 33µs CP, 2 for 100µs CP and 4 for 200µs CP

Table 5: Simulation parameters and assumptions.

The channel model selected in this contribution is the TDL-B as detailed in TS 38.901 with a Delay Spread (DS) of 20µs which has been obtained according to SLS in [5].

Regarding the real channel estimation type at the receiver, the UE performs independent one-dimensional linear interpolation in time and frequency domains. For the Rel-14 numerology with 7.5 kHz of subcarrier spacing (33.3µs CP) the receiver first performs linear interpolation in frequency domain followed by linear interpolation in time domain.

For the Rel-14 numerology with 1.25 kHz of subcarrier spacing (200µs CP) and the candidate numerology with 2.5 kHz of subcarrier spacing (100µs CP) the receiver first performs linear interpolation in time domain followed by linear interpolation in frequency domains. For these two numerologies the receiver stores 4 and 2 subframes, respectively, before the channel estimation can be calculated, which increases the memory requirements at the receivers.

The MCS is selected to provide a spectral efficiency ~1bps/Hz and that operates at SNR values close to the ones calculated in the coverage simulations section.

4.3.2 Simultion Results

Figures 8-10 show the LLS results for the three considered UE speeds of 60km/h, 120km/h and 250km/h, respectively.

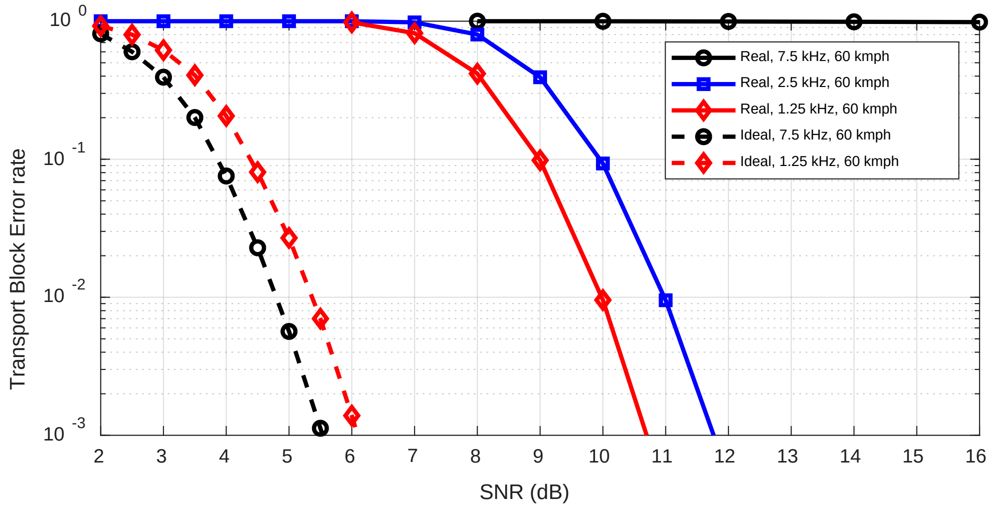


Figure 8: Transport block error rate vs. SNR (dB) for Rel-14 numerologies with subcarrier spacing of 7.5 kHz (33.3µs CP) CP and 1.25 kHz (200µs CP) and a potential enhancement with a subcarrier spacing of 2.5 kHz (100µs CP) in TDL-B channel model with a Delay Spread of 20µs with 60 km/h user speed. The performance of the numerologies with ideal and realistic channel estimation is included.

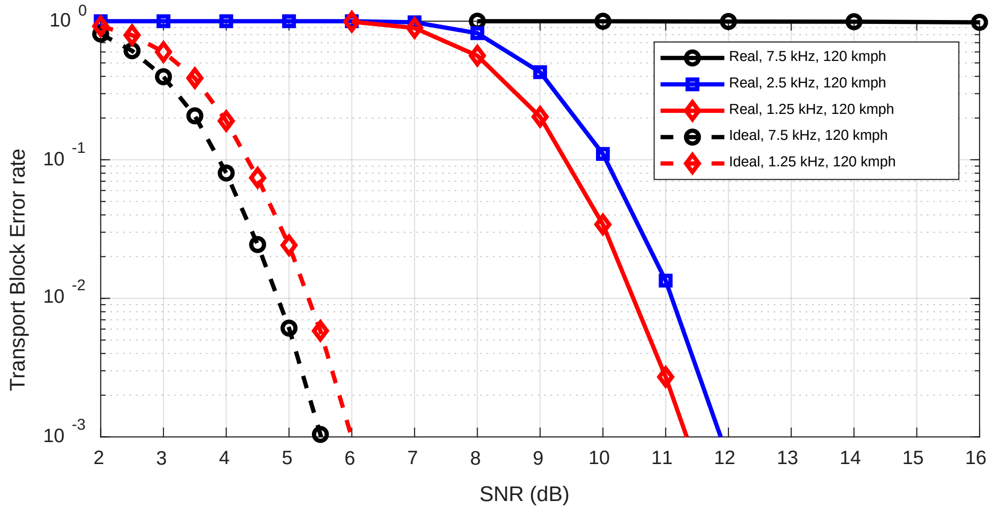


Figure 9: Transport block error rate vs. SNR (dB) for Rel- numerologies with subcarrier spacing of 7.5 kHz (33.3µs CP) CP and 1.25 kHz (200µs CP) and a potential enhancement with a subcarrier spacing of 2.5 kHz (100µs CP) in TDL-B channel model with a Delay Spread of 20µs with 120 km/h user speed. The performance of the numerologies with ideal and realistic channel estimation is included.

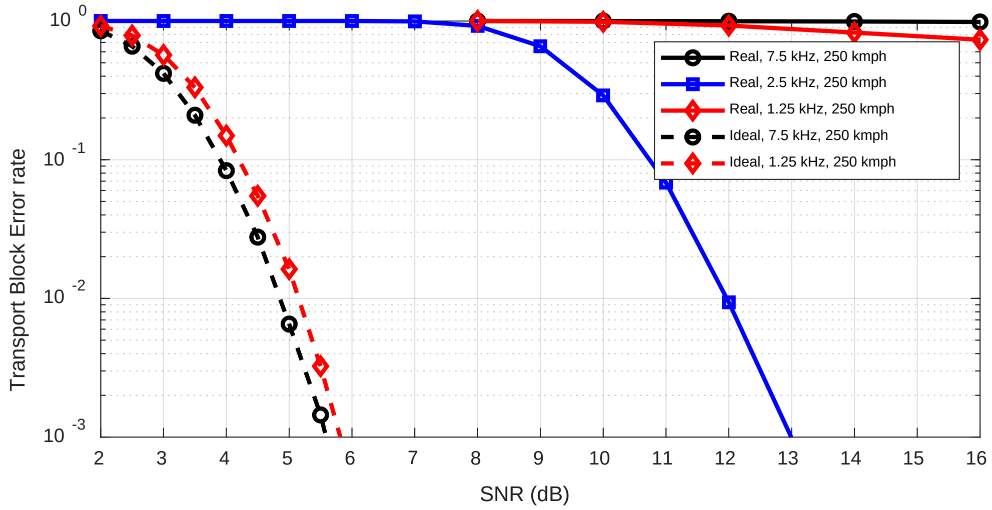


Figure 10: Transport block error rate vs. SNR (dB) for Rel-14 numerologies with subcarrier spacing of 7.5 kHz (33.3µs CP) CP and 1.25 kHz (200µs CP) and a potential enhancement with a subcarrier spacing of 2.5 kHz (100µs CP) in TDL-B channel model with a Delay Spread of 20µs with 250 km/h user speed. The performance of the numerologies with ideal and realistic channel estimation is included.

From the results, it can be seen that there is a significant gap between the performance with ideal and realistic channel estimation. It is important to note that while the assumption of ideal channel estimation provides optimistic results, the results with real channel estimation using a very simple linear interpolator in time and frequency domains provide pessimistic results. It is expected that a more sophisticated receiver would provide a performance that would lie between the two types of channel estimation assumptions shown in these results. We also expect that an improvement due to a better channel estimation would improve the performance of all the considered numerologies. Hence, the performance difference between the different numerologies with better channel estimation algorithms would show differences similar to the ones shown in this contribution.

With ideal channel estimation, the numerology with 7.5 kHz subcarrier spacing outperforms the 1.25 kHz numerology due to the lower density of RS for the former (i.e. lower code-rate) with 18 and 24 resource elements with RS per Resource Block, respectively. (At the time of writing this contribution, results with 2.5 kHz subcarrier spacing are not available due to lack of sufficient simulation time.) With the assumed RS density for the candidate 2.5 kHz subcarrier spacing numerology with 36 resource elements with RS per Resource Block, we expect a further performance degradation in comparison with the 1.25 kHz subcarrier numerology.

With real channel estimation, the results are very different that those with ideal channel estimation. It can be seen that the numerology with 7.5 kHz subcarrier spacing is not able to decode even for 60 km/h. This is due to the very large Delay Spread of the channel of 20µs. In this channel (TDL-B) the last taps are delayed close to 90µs that are far beyond the equalisation interval of this numerology (i.e. 33.3µs). Hence, this numerology, although it could provide very high speeds, is not suitable for the LPLT networks considered with large inter-site distances.

Observation 11: The Rel-14 numerology with 7.5 kHz subcarrier spacing (33.3 µs CP) is not able to operate in the considered LPLT networks due to the large Delay Spread of the network.

If we compare the performance of baseline Rel-14 numerologies with 1.25 kHz subcarrier spacing (200 µs CP) with the candidate 2.5 kHz subcarrier spacing (100 µs CP), we can observe that for 60 km/h and 120 km/h, the 1.25 kHz subcarrier numerology provides better performance due to larger equalisation interval and more parity bits due to lower RS overhead. It is interesting to note that the difference between the two numerologies reduces for 120 km/h.

At 250 km/h the Rel-14 baseline numerology with 1.25 kHz subcarrier spacing (200 µs CP) suffers a significant performance degradation due to the narrow subcarrier spacing relative to the Doppler spread relative that makes the transmission mode non-decodable.

Observation 12: The Rel-14 numerology with 1.25 kHz subcarrier spacing (200 µs CP) is not able to operate in high speed mobility scenarios with 250 km/h in the considered LPLT networks.

On the other hand, the candidate numerology with 2.5 kHz subcarrier spacing (100 µs CP) permits reception at such high speeds.

Observation 13: A numerology with 2.5 kHz subcarrier spacing (100 µs CP) is able to operate in high speed mobility scenarios with 250 km/h in the considered LPLT networks.

5. Subcarrier Spacing in DTT Broadcasting Standards

For any new numerologies with a longer T_u it is important to consider the minimum ICS that may be used in real environments so as to provide adequate Doppler performance.

This section provides some background information on the ICS of DVB-T2 and ATSC 3.0, which are similarly based on COFDM. The experience gained from deployments of these systems may help to inform the design of further eMBMS modes targeted at fixed rooftop reception, particularly with respect to the minimum ICS.

DVB-T2 has ICS of 209 Hz, 244 Hz and 279 Hz for a 32k FFT in 6, 7 and 8 MHz bandwidths respectively.

The 279 Hz variant has now been deployed for a number of years in a number of countries with no known Doppler issues with respect to fixed rooftop reception. The UK is one example [6]. Similarly, the 209 Hz variant has been deployed in Colombia with no known issues.

ATSC 3.0 has an ICS of 210 Hz for a 32k FFT in a 6 MHz bandwidth, with no known Doppler issues.

Observation 14: DVB-T2 and ATSC 3.0 have numerologies with ICS of as low as 209 Hz. These numerologies have no known Doppler performance issues for fixed rooftop reception.

6. Summary

Based on the observations made in this document it would be worthwhile standardising new numerologies in order to better support fixed rooftop reception. Potential new numerologies would have a T_u of 2.6 ms or more (ideally 4ms or more), and CPs of 300 µs or more, preferably 400 µs or longer. Numerologies such as these would improve the SE for all of the networks investigated: LPLT, MPMT and HPHT1. The design of new numerologies should be based on SE optimisation, taking into account factors such as the RS pattern and CP overheads

Recommendation 1: At least one new numerology with a longer CP and T_u should be standardised to improve the SE for fixed rooftop reception in the LPLT, MPMT and HPHT1 networks. The CP and T_u should be at least 300 µs and 2.6ms respectively. Ideally they would be longer, at around 400 µs and 4ms or more, respectively.

Link level simulations, with the simplistic receiver considered, show that the Rel-14 numerologies would not meet the 250 km/hr mobility target with adequate SINR in the LPLT network relevant to this study item. A 100 µs CP and 400 µs T_u, would, however, meet the 250 km/hr target. An additional numerology with a shorter 100 µs CP and 400 µs T_u should therefore be standardised for this use case.

Recommendation 2: A new numerology with a shorter, 100µs CP and 400 µs T_u should be standardised in order to provide better mobility in the LPLT network for car mounted reception.

Recommendation 3: New numerology design should, as far as is practicable, be based on SE optimisation, taking into account factors such as the RS pattern and CP overheads

References

[1]. RP-181706; "Study on LTE-based 5G Terrestrial Broadcast"; Qualcomm Inc.; 3GPP TSG RAN #81, Gold Coast, Australia, September 2018.

[2]. R1-1811728; Chairman's notes of AI 6.2.4 Study on LTE-based 5G Terrestrial Broadcast; Ad-Hoc chair (Ericsson); 3GPP RAN WG1 #94-Bis; Chengdu, China; October 2018

[3]. R1-1609978; Design Options for Longer Cyclic Prefix and Link Level Simulation Results; Qualcomm Inc.; 3GPP TSG RAN #86b; Lisbon, Portugal; October 2016

[4]. R1-1811588; Scenarios and simulation assumptions for the LTE based terrestrial broadcast gap analysis; EBU, BBC, IRT; 3GPP RAN WG1 #94-Bis; Chengdu, China; October 2018

[5]. R1-1813727; Evaluation results and potential enhancements; Qualcomm; 3GPP RAN WG1 #95; Spokane, USA; November 2018

[6]. Reference Parameters for Digital Terrestrial Television Transmissions in the United Kingdom; Ofcom; November 2016

Acknowledgements

This work was supported in part by the European Commission under the 5G-PPP project Broadcast and Multicast Communication Enablers for the Fifth-Generation of Wireless Systems 5G-XCast (H2020-ICT-2016-2 call, grant number 761498). The views expressed in this contribution are those of the authors and do not necessarily represent the project.

3GPP TSG RAN WG1 Meeting #96-Bis R1-1905330

Xi'an, China 8th April – 12st April 2019

Agenda item: **6.2.4.2**

Source: EBU, BBC, IRT

Title: Network Simulations Regarding the Performance of the CAS

Document for: Discussion

1. Introduction

The New WID on LTE-based 5G terrestrial broadcast [1] states that 3GPP should "*Specify, if found necessary, enhancements to the physical channels and signals in the CAS [RAN1, RAN4]*"

This document summarises further work that has been carried out to better understand the minimum required SINR that the CAS would have to meet in order to ensure robust reception in various combinations of network (LPLT, MPMT, HPHT) and reception type (car mounted and fixed rooftop). The document also summarises investigations carried out in order to determine the effect that different UE FFT window positioning strategies and receiving antenna alignment methodologies may have on the SINR requirements for the CAS.

2. Background

The simulations in this document have been carried out according to the framework set out in [2] and in conjunction with the clarifications below.

2.1 Receiver Synchronisation

As only one MBSFN area is considered in the simulations it has been assumed that a UE may attempt to synchronise with the network by finding the strongest CAS at each particular location, irrespective of which transmitter the CAS originates from. For the simulations in this document, this assumption implies that, once found, the strongest CAS at each location would be defined as the wanted signal.

2.2 Model of Signals' Variation in Time

Two different time models have been used in this document: the 50/50 and 50/1 wanted/interferer models as described in [2]. The 50/1 nomenclature, for example, means the wanted signals are computed at their 50% time levels while the interferers are computed at 1% time.

2.3 FFT Window Positioning Strategy

In SFN the receiver will 'see' a number of signal echoes with various delays and amplitudes depending on the receiving location and geometry of the network. Different strategies may be used to position the receiver's FFT window in the presence of such echoes. As different positioning strategies may affect the outcome of coverage simulations, and none has been defined in [2], three common strategies have been investigated in this paper, as described below and illustrated in figure 1.

- **First Signal Above Threshold:** the beginning of the FFT window is positioned to align with the first echo received above a threshold.
- **Strongest Signal:** the beginning of the FFT window is positioned to align with the strongest echo received.

- **Maximum Energy in CP:** the beginning of the FFT window is positioned in order to maximise the amount of energy from the received echoes that falls within the duration of the CP.

In general, it is expected that the maximum energy window strategy would provide a higher received SINR throughout the network compared with the other two while the first above a threshold noise strategy would provide the lowest.

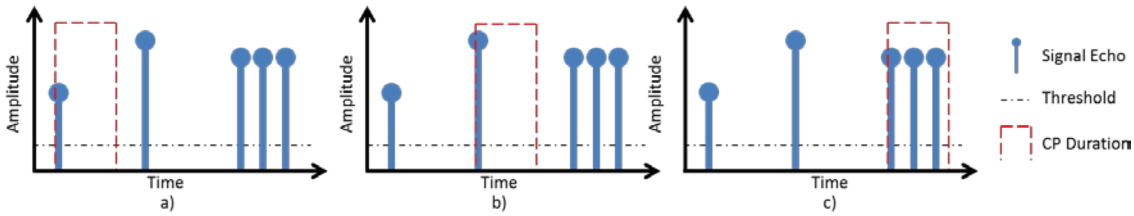


Figure 1: FFT Window Positioning Strategies. a) First Signal Above a Threshold b) Strongest Signal. c) Maximum Energy in CP

2.4 CAS Configuration (Single Cell vs SFN)

Two main ways of configuring the CAS in a network have been considered in this document: Single Cell and SFN, as described below.

2.4.1 Single Cell

In this configuration each site or sector in the network transmits (on the same frequency) a unique CAS (e.g. with different physical cell identities). In this configuration the CAS would not, therefore, form a conventional SFN, and the CAS from each transmitter would interfere with, and suffer interference from, the CAS from all other transmitters in the network. Two further sub-configurations of single cell have been considered in this document.

- **Three Independent Sectors per Site**: every sector at every site transmits a unique CAS. Independent unicast from each sector is therefore possible.

- **Three Sectors in SFN at each Site:** all three sectors at each site are synchronised and transmit the same CAS, forming an SFN between the three sectors at each site. Each site would transmit a different CAS, and thus the CAS from each site would interfere with each other.

2.4.2 SFN

In this configuration all the sites and sectors within the network transmit the same CAS, forming a conventional SFN. Throughout this document the 16µs CP has been used to model the CAS SFN.

2.5 99th Percentile for Area Coverage

European broadcasters often have obligations to provide terrestrial television services to 99% or more of the population [3], and radio services to similar levels of population and road coverage. For this reason, this document considers that the 99th percentile of coverage throughout the network is a suitable target. The 95th percentile has been documented for completeness.

3. CAS Car Mounted

In this section the CAS is investigated for the car mounted scenario. Throughout this section the wanted signal has been defined as the strongest signal after location variation.

3.1 Single Cell

Table 1 shows the SINR achievable for the 95th and 99th percentile for a number of single cell scenarios aimed at car mounted reception. As can be seen from the table, the achievable SINR is sensitive to the time-model that is used and the scenario that is modelled. The conventional 50/1 model indicates the CAS would need to be more robust than indicated by the 50/50 model. The HPHT1 scenario is the most onerous with the 50/1 model while LPLT is more onerous with the 50/50 model.

Network Topology	Tx Antenna	FFT Synchronisation Strategy	95th Percentile Entire Area		99th Percentile Entire Area	
			50/50	50/1	50/50	50/1
LPLT 3 Sector SFN	Sectorised	1st above a threshold	-2.2	-5.2	-4.0	-7.1
LPLT 3 Sector SFN	Sectorised	Strongest	-2.1	-5.2	-4.0	-7.0
LPLT 3 Sector SFN	Sectorised	Max energy window	-2.1	-5.2	-4.0	-7.0
LPLT 3 Independent Sectors	Sectorised	N/A	-2.9	-5.8	-4.6	-7.7
MPMT	Omni	N/A	-1.0	-5.5	-2.8	-7.4
HPHT1	Omni	N/A	-0.3	-9.0	-2.3	-11.1

Table 1: Achievable SINR for car mounted single cell.

Observation 1: For car mounted reception in single cell networks the achievable SINR of the CAS is dependent on the time model (50/50 or 50/1) and the scenario (e.g. HPHT1, MPMT or LPLT).

3.2 SFN

This section investigates the performance of the CAS where all transmitters in the network operate in an SFN (16µs CP). Simulation results for the three different FFT window positioning strategies are summarised in table 2.

FFT Window Positioning Strategy	Network Topology	Tx Antenna	95th Percentile Entire Area		99th Percentile Entire Area	
			50/50	50/1	50/50	50/1
First above a threshold	LPLT	Sectorised	3.6	0.1	0.0	-3.4
	MPMT	Omni	-1.5	-6.3	-6.8	-11.3
	HPHT1	Omni	-1.3	-10.7	-7.1	-16.5
Strongest signal	LPLT	Sectorised	0	-2.7	-2.4	-5.1
	MPMT	Omni	-0.3	-4.7	-2.4	-6.9
	HPHT1	Omni	-0.2	-8.4	-1.9	-10.9
Maximum energy	LPLT	Sectorised	3.3	-0.1	0.0	-2.9
	MPMT	Omni	0.4	-4.0	-1.4	-6.2
	HPHT1	Omni	0.6	-8.1	-1.4	-10.5

Table 2: Achievable SINR for car mounted reception in SFN

Table 2 shows that the achievable SINR for car mounted reception in SFN is also dependent on the time model used, with the 50/1 model being more onerous than the 50/50 model. The network topology also has a significant influence of the achievable SINR for the CAS in the network.

The FFT window positioning strategy also has a significant impact on the achievable SINR for the CAS in the network where the maximum energy FFT positioning method would provide the highest SINR in almost every case (all but one). Therefore, when determining the performance requirement of the CAS in SFN it is important to clearly state which FFT positioning strategy is to be used. Furthermore, in the case of broadcasting it may be necessary for the standards to reflect this finding should the FFT window positioning strategy be fundamental to meeting the CAS performance requirements.

Observation 2: For car mounted reception in SFN the achievable SINR of the CAS is dependent on the time model (50/50 or 50/1) and the scenario (e.g. HPHT1, MPMT or LPLT).

Observation 3: For car mounted reception in SFN the achievable SINR of the CAS is sensitive to the UE's FFT window positioning strategy.

4. Fixed Rooftop

4.1 Receiving Antenna Alignment

A number of different receiving antenna alignment strategies are possible for simulations involving fixed rooftop antenna, each of which may affect the results. Two strategies (described below) have been considered in this document.

- **Strongest transmitter before location variation**: the main lobe of the receiving antenna is aligned to the transmitter providing the highest signal strength at the receiving location before location variation is added. Due to the regular nature of the transmitter networks used herein and the monotonic decay of the ITU-R P.1546-5 field strength with distance, aligning the receiving antenna to the strongest transmitter before location variation is equivalent to aligning it to the closest transmitter.

- **Strongest transmitter after location variation**: the main lobe of the receiving antenna is aligned to the transmitter that provides the strongest signal at the receiving location, after location variation has been applied.

Once the receiving antenna has been aligned and the received signals have been adjusted accordingly, the strongest signal is then taken to be the wanted signal.

[4] sets out that it is desirable to avoid the need to realign receiving antennas in situations where they already exist. The strongest transmitter before location variation method may therefore be best suited for modelling these situations while the strongest transmitter after location variation may be more suitable for modelling green field situations where there is no need to consider the existing population of installed receiving antennas. Results for both methodologies have therefore been presented below.

4.2 Single Cell

Table 3 shows the SINR achievable for the 95th and 99th percentile for a number of single cell scenarios aimed at fixed rooftop reception. As can be seen from the table, the achievable SINR is, again, sensitive to the time-model that is used. Although the most onerous case for single cell fixed rooftop reception would be LPLT with three independent sectors and receiving antenna alignment before location variation, this use case may not need further consideration as there are unlikely to be any legacy networks for which support for this mode will be required.

The most critical case therefore appears to be MPMT independent sectors case in which receiving antennas are aligned to the strongest signal before location variation.

Rx Antenna Alignment	Network Topology	Tx Antenna	FFT Synchronisation Strategy	95th Percentile Entire Area		99th Percentile Entire Area	
				50/50	50/1	50/50	50/1
Strongest b. LV	LPLT 3 Sector SFN	Sectorised	1st above a threshold	6.7	7.2	1.9	3.8
Strongest b. LV	LPLT 3 Sector SFN	Sectorised	Strongest	6.7	7.2	1.9	3.8
Strongest b. LV	LPLT 3 Sector SFN	Sectorised	Max energy window	6.7	7.2	1.9	3.8
Strongest b. LV	LPLT 3 Ind. Sectors	Sectorised	N/A	-2.1	0.5	-8.7	-1.7
Strongest b. LV	MPMT	Omni	N/A	8.4	2.8	2.6	-2.8
Strongest b. LV	HPHT1	Omni	N/A	11.2	1.1	4.8	-5.0
Strongest a. LV	LPLT 3 Sector SFN	Sectorised	1st above a threshold	11.7	7.2	8.5	3.8
Strongest a. LV	LPLT 3 Sector SFN	Sectorised	Strongest	11.7	7.2	8.5	3.8
Strongest a. LV	LPLT 3 Sector SFN	Sectorised	Max energy window	11.7	7.2	8.5	3.8
Strongest a. LV	LPLT 3 Ind. Sectors	Sectorised	N/A	2.3	0.5	0.2	-1.7
Strongest a. LV	MPMT	Omni	N/A	14.5	7.6	12.4	4.3

Strongest a. LV	HPHT1	Omni	N/A	16.2	6.0	14.4	3.3

Table 3: Achievable SINR for single cell, fixed rooftop reception

Observation 4: For fixed rooftop reception in single cell networks the achievable SINR of the CAS is dependent on the time model (50/50 or 50/1), the scenario (e.g. HPHT1, MPMT or LPLT), and the receiving antenna alignment methodology.

4.3 SFN

Table 4 shows the SINR achievable for the 95th and 99th percentile for a number of scenarios aimed at fixed rooftop reception in CAS SFN (16µs CP). As can be seen from the table, for each type of network the achievable SINR is again sensitive to the time-model that is used, the receiving antenna alignment methodology and the FFT window positioning strategy.

Rx Antenna Alignment	FFT Synchronisation Strategy	Network Topology	Tx Antenna	95th Percentile Entire Area		99th Percentile Entire Area	
				50/50	50/1	50/50	50/1
Strongest b. LV	1st above a threshold	LPLT	Sectorised	10.9	8.2	6.3	4.3
Strongest b. LV	1st above a threshold	MPMT	Omni	12.3	4.8	7.3	0.1
Strongest b. LV	1st above a threshold	HPHT1	Omni	14.0	3.1	7.6	-2.9
Strongest a. LV	1st above a threshold	LPLT	Sectorised	12.6	7.6	7.0	2.2
Strongest a. LV	1st above a threshold	MPMT	Omni	-15.3	-20.2	-22.0	-26.5
Strongest a. LV	1st above a threshold	HPHT1	Omni	-14.9	-25.0	-22.7	-32.2
Strongest b. LV	Strongest	LPLT	Sectorised	9.3	8.2	4.0	4.3
Strongest b. LV	Strongest	MPMT	Omni	12.1	4.7	6.6	-0.4
Strongest b. LV	Strongest	HPHT1	Omni	14.0	3.1	7.6	-2.9
Strongest a. LV	Strongest	LPLT	Sectorised	12.5	7.9	9.0	4.1
Strongest a. LV	Strongest	MPMT	Omni	15.0	7.8	12.7	4.4
Strongest a. LV	Strongest	HPHT1	Omni	16.6	6.3	14.6	3.6
Strongest b. LV	Max energy window	LPLT	Sectorised	10.9	8.2	6.3	4.3
Strongest b. LV	Max energy window	MPMT	Omni	12.2	4.8	7.2	0.1
Strongest b. LV	Max energy window	HPHT1	Omni	14.1	3.2	7.9	-2.7
Strongest a. LV	Max energy window	LPLT	Sectorised	13.2	8.2	9.3	4.3
Strongest a. LV	Max energy window	MPMT	Omni	15.5	8.0	13.0	4.5
Strongest a. LV	Max energy window	HPHT1	Omni	16.9	6.5	14.9	3.7

Table 4: Achievable SINR for CAS SFN, fixed rooftop reception

Should it be possible to rely on receivers operating with the maximum energy window FFT algorithm, the most onerous case for single cell fixed rooftop reception would be the HPHT1 case under the strongest transmitter before location variation antenna alignment strategy. In this situation the achievable SINR for the CAS is 7.9 dB with the 50/50 model and -2.7dB with the 50/1 model. The achievable SINR would improve significantly should it be possible to align the receiving antenna to the strongest possible signal at each location: 14.9dB for 50/50 and 3.7dB for 50/1.

Observation 5: For fixed rooftop reception in SFN the achievable SINR of the CAS is dependent on the time model (50/50 or 50/1), the scenario (e.g. HPHT1, MPMT or LPLT), the receiving antenna alignment methodology, and the UE's FFT window positioning strategy.

6. Summary

Network simulations have been carried out for a large number of network configurations, receiving environments and a number of other assumptions such as UE FFT window positioning in SFN strategies and receiving antenna alignment . Based on these simulations the following observations have been made:

Observation 1: For car mounted reception in single cell networks the achievable SINR of the CAS is dependent on the time model (50/50 or 50/1) and the scenario (e.g. HPHT1, MPMT or LPLT).

Observation 2: For car mounted reception in SFN the achievable SINR of the CAS is dependent on the time model (50/50 or 50/1) and the scenario (e.g. HPHT1, MPMT or LPLT).

Observation 3: For car mounted reception in SFN the achievable SINR of the CAS is sensitive to the UE's FFT window positioning strategy.

Observation 4: For fixed rooftop reception in single cell networks the achievable SINR of the CAS is dependent on the time model (50/50 or 50/1), the scenario (e.g. HPHT1, MPMT or LPLT), and the receiving antenna alignment methodology.

Observation 5: For fixed rooftop reception in SFN the achievable SINR of the CAS is dependent on the time model (50/50 or 50/1), the scenario (e.g. HPHT1, MPMT or LPLT), the receiving antenna alignment methodology, and the UE's FFT window positioning strategy.

The observations above, combined with the wide range of results from the simulations lead to the following recommendations:

Recommendation 1: The UE's FFT window positioning strategy should be unambiguous, and as optimal as possible (e.g. it should maximise the energy in the CP window, or better).

Recommendation 2: A single time-model should be established for the assessment of the CAS.

Recommendation 3: A consensus should be reached around whether single cell or SFN CAS networks should be used.

References

[1]. RP-190134; "New WID on LTE-based 5G terrestrial broadcast"; Qualcomm Incorporated; 3GPP TSG RAN Meeting #83; Shenzhen, China; March, 2019

[2]. 3GPP TR 36.776; "Study on LTE-based 5G terrestrial broadcast (Release 16)"; 3GPP; March 2019

[3]. R1-1810319; "Public service broadcaster requirements and background information relevant to LTE-based 5G Terrestrial Broadcast"; EBU, BBC, IRT; 3GPP RAN WG1 #94-bis, Chengdu, China; October 2018

[4]. R1-1812430; "Evaluation Results for LTE-Based 5G Terrestrial Broadcast"; EBU, BBC, IRT; 3GPP RAN WG1 #95; Spokane; USA, November 2018

Acknowledgements

This work was supported in part by the European Commission under the 5G-PPP project Broadcast and Multicast Communication Enablers for the Fifth-Generation of Wireless Systems 5G-XCast (H2020-ICT-2016-2 call, grant number 761498). The views expressed in this contribution are those of the authors and do not necessarily represent the project.

3GPP TSG RAN WG1 Meeting #96-Bis R1-1905331

Xi'an, China 8th April – 12st April 2019

Agenda item: **6.2.4.2**

Source: EBU, BBC, IRT

Title: Information For Time Variation Models

Document for: Discussion

1. Introduction

The New WID on LTE-based 5G terrestrial broadcast [1] states the following:

Specify, if found necessary, enhancements to the physical channels and signals in the CAS [RAN1, RAN4]

- *This objective includes determining a realistic modelling for the time variation of the desired and interfering signals (e.g. a model between the 50%/50% and 50%/1%), and identifying based on the modelling what channels and signals (if any) need to be enhanced.*

ITU Working Party 3K document 6A/198-E [2] contains information on how signals vary over time and how the variation may be taken into account in network simulations by way of using Monte Carlo in the time domain. The document is therefore put forward for consideration in the development of an enhanced time variation model for use in the assessment of the CAS.

For convenience the 3K document [2] has been copied into Annex 1.

References

[1]. RP-190134; "New WID on LTE-based 5G terrestrial broadcast"; Qualcomm Incorporated; 3GPP TSG RAN Meeting #83; Shenzhen, China; March, 2019.

[2]. 6A/198-E; Liaison statement to Working Party 6a, Report on the work of correspondence group 3K-4 concerning the correlation of short term interfering signals; ITU, March 2013.

Acknowledgements

This work was supported in part by the European Commission under the 5G-PPP project Broadcast and Multicast Communication Enablers for the Fifth-Generation of Wireless Systems 5G-XCast (H2020-ICT-2016-2 call, grant number 761498). The views expressed in this contribution are those of the authors and do not necessarily represent the project.

Annex 1: ITU Document 6A/198-E

The document follows overleaf.

Subject: Document 3K/34

Document 6A/198-E

13 March 2013

English only

Chairman, Working Party 3K

LIAISON STATEMENT TO WORKING PARTY 6A

REPORT ON THE WORK OF CORRESPONDENCE GROUP 3K-4 CONCERNING THE CORRELATION OF SHORT TERM INTERFERING SIGNALS

The Chairman, Working Party 3K (WP 3K) thanks Working Party 6A (WP 6A) for its liaison statement requesting further information on the progress of studies relevant to the correlation of short term interfering signals (Document 3K/34). This document is the latest in an on-going exchange of liaison statements between WP 3K and WP 6A on this topic: see also Docs. 3K/22, 6A/95 and 6A/162. The principal issue of concern is the extent to which correlation (in probability) of elements of the aggregate of temporally varying interfering signals should be assumed. As a matter of considerable urgency, Correspondence Group 3K-4 (CG 3K-4) has been conducting extensive studies on methods for the aggregation of short term interfering signals and the CG has now arrived at several noteworthy conclusions. Because WP 6A meets next in April 2013, while WP 3K will not meet until June 2013, a report of the work of CG 3K-4 is given below in Annex 1, including descriptions of two recommended methods by which the aggregate of temporally varying interfering signals may be evaluated.

WP 3K is cognizant that the general method given in Annex 1 is more numerically intensive than the simple method, also given there. However, it is believed that this cost is outweighed by the benefits of broader applicability of the general method to arbitrary time percentages and the potential to adapt the method to different degrees of correlation between different elements of the temporally variable aggregate. WP 3K would welcome additional comments and questions from WP 6A on this topic.

Status: For action

Contact: Paul McKenna **Email:** mckenna@its.bldrdoc.gov

Annex: 1

ANNEX 1

Methods for the aggregation of short-term interfering signals

Introduction

CG 3K-4 have been tasked with providing advice to WP 6A regarding methods for the estimation of aggregate interference from multiple sources in the general case where complete temporal correlation cannot be assumed.

This document describes the methods recommended by WP 3K for use in the studies being conducted by WP 6A concerning potential interference to UHF television services.

A general method is specified that should be used in any Monte-Carlo simulations, and is applicable at any desired percentage-time value; a simple alternative is provided only for cases where computational complexity must be avoided.

Proposed methods

Two methods for the computation of aggregate interference from multiple transmitters where individual path losses are temporally variable are recommended.

The first approach ('general method') is based on a rigorous mathematical treatment of the joint variability of multiple paths, and can be used to estimate the aggregate received power at any percentage-time. The method uses Monte Carlo simulation involving multiple calculations for each path of interest, and would be appropriate for use in a situation where numerically-intensive computer simulation is already envisaged, such as the model given in Document 6A/73, Annex 9, Appendix 2[2].

Recognising that this approach may not always be appropriate (e.g. where a quick estimate is required without an iterative computer simulation), a simple alternative is also proposed ('simple method'). This method is currently only defined for the case where the aggregate power is to be estimated at 1% time, although it could be readily extended for use at other percentage-times. The method is also appropriate for use within the simulation framework given in Document 6A/73, Annex 9, Appendix 2.

Background information on the methods is provided in Appendices A and B. A brief summary of the work within the CG 3K-4, and the reasons for the selection of the proposed methods rather than the alternative proposals is given in Appendix C.

General method

The method is described in the following pseudo-code (where RV is a 'random variable', CDF the 'cumulative distribution function', and α is a constant, discussed below):

[2] Also see Report ITU-R BT.2265 (11/2012).

1 FOR *trial* = 0…*number_of_trials*

2 {

3 set power sum for this trial, P_{trial}, to zero

4 get initial RV,µ1, from uniform distribution in range 0-1

5 FOR *tx* = 1…*number_of_tx*

6 {

7 get RV, ν, from uniform distribution in range 0-1)

8 derive new RV, $\mu_2 = \mu_1 \left(\nu^{-\alpha/(\alpha+1)} - 1 + \mu_1^{\alpha} \right)^{-1/\alpha}$

9 get received power, P_n, from transmitter *tx* at %-time = µ2*100

10 add P_n to power sum, P_{trial}

11 }

12 Add P_{trial} to *result_array*

13 }

14 Make CDF of *result_array*

15 Find 0.01 probability point on CDF (corresponds to 1% aggregate power)

The constant α determines the degree of 'correlation' between loss values on the different paths . On the basis of the limited empirical data available a value of 1.0 should be used.

Careful attention must be paid to the choice of *number_of_trials*. As is the case for the location probability modelling described in Document 6A/73, Annex 9, Appendix 2, the number of trials must be sufficient to give a confidence interval appropriate for the scenario under investigation.

Note that although the pseudo-code is couched in terms of received power the results may need to be expressed as an aggregate field strength for use in the WP 6A simulations.

Propagation model

In line 9 of the pseudo-code, the received power from a single transmitter is calculated, and this calculation will need to take into account transmitter EIRP, transmitter and receiver antenna directivity, receive antenna gain and the basic transmission loss.

The latter can be determined using any appropriate propagation model that takes percentage time as an input parameter.

Unfortunately the majority of ITU-R models (e.g. Recommendation ITU-R P.1546) are not directly suitable for use in Monte Carlo simulation of temporal behaviour, as they are only defined for use over a limited temporal range (e.g. 1% - 50% for Recommendation ITU-R P.1546). The only exception is Recommendation ITU-R P.2001, which is designed for use in precisely the type of simulation discussed here.

Should it be required to use Recommendation ITU-R P.1546 to perform these simulations, the following changes will be required:

- For any time greater than 50%, the model should return the loss value for 50.0%.
- The model should be allowed to return loss values for arbitrarily small percentage times by allowing the existing log-normal interpolation function to extrapolate below 1%. The only change required to Recommendation ITU-R P.1546 should be the removal of the 1% limit.

It should be emphasised that the values returned by the model at >50% and <1% are not valid in themselves; these modifications are simply required to allow the use of Recommendation ITU-R P.1546 in a Monte Carlo framework and any errors introduced in the estimation of aggregate power between 1% and 50% time are expected to be insignificant.

Computational issues

The implementation indicated above is only the most simple, and several tactics to make the code faster could be implemented.

For example, most computation time will be expended in line 9, the call to the propagation model. As the (*number_of_tx*) transmission paths do not change in the course of the computation, it would be worthwhile pre-computing the distribution of path loss with time for each path, and storing this as a look-up table or polynomial fit.

It may be possible to combine the modelling of temporal variability with that of location variability in a computationally-efficient manner; this issue has not been studied by the correspondence group, but may form the basis of further work.

Simple method

In this approach, the calculation of aggregate power is made, as presently proposed in Doc. 6A/73, Annex 9, Appendix 2 by simply taking the power sum of the individual interferers (i.e. assuming full correlation between paths).

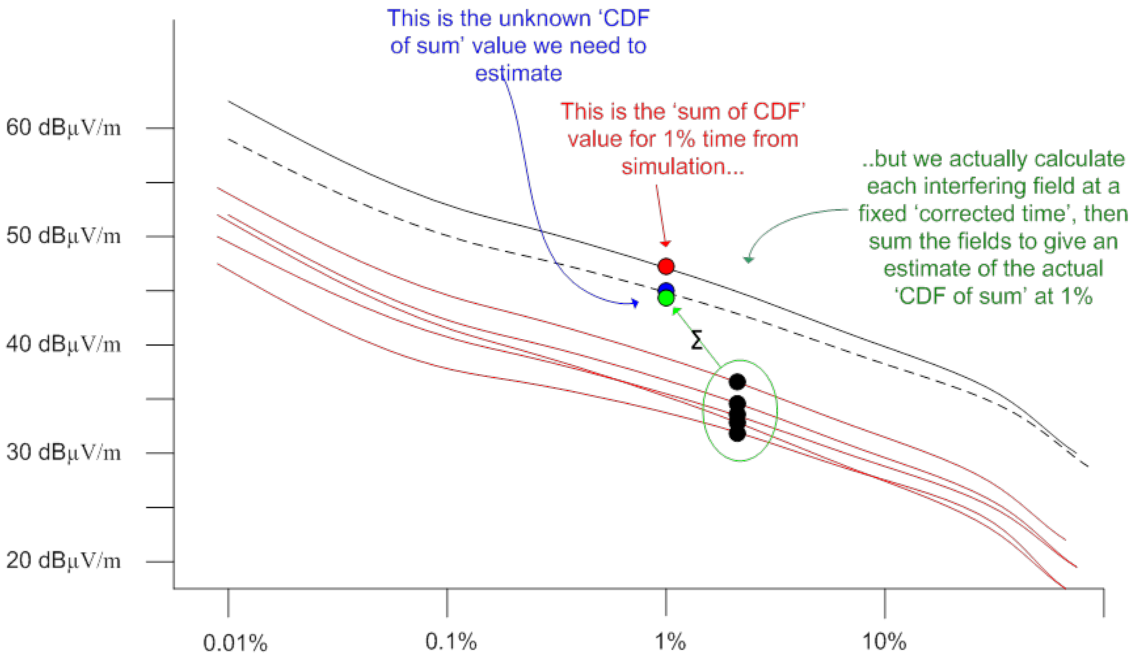
However, although the aggregate power exceeded at 1% time is to be calculated, the individual path loss calculations are made at a ‘corrected time’ which reflects the de-correlation between interference paths.

Based on the limited empirical data available (see Appendix C), a ‘corrected time’ of 1.75 % should be used to give an estimate of aggregate power at 1.0 % time.

The procedure of the simple method is sketched below.

FIGURE 2.1

The 'simple method'



Comparison of methods

Simulations using the 'general' model have been made for three simple cases, as set out in Table 2.1.

TABLE 2.1

Test scenarios

Name	Number of tx	Path lengths	Effective tx heights
'longer paths'	42	50 km – 134 km	30 m (fixed)
'shorter paths'	100	20 km – 70 km	10 m – 60 m
'large spread'	200	100 km – 300 km	50 m – 450 m

In all cases the frequency assumed was 500 MHz and the receive height 3m.

The overall results for the three cases are shown in Figures 2.2 – 2.4 below. The dependence of the aggregate field on the assumed value of α (i.e. the degree of mutual correlation between paths) is clearly seen.

FIGURE 2.2

‘Longer paths’ case

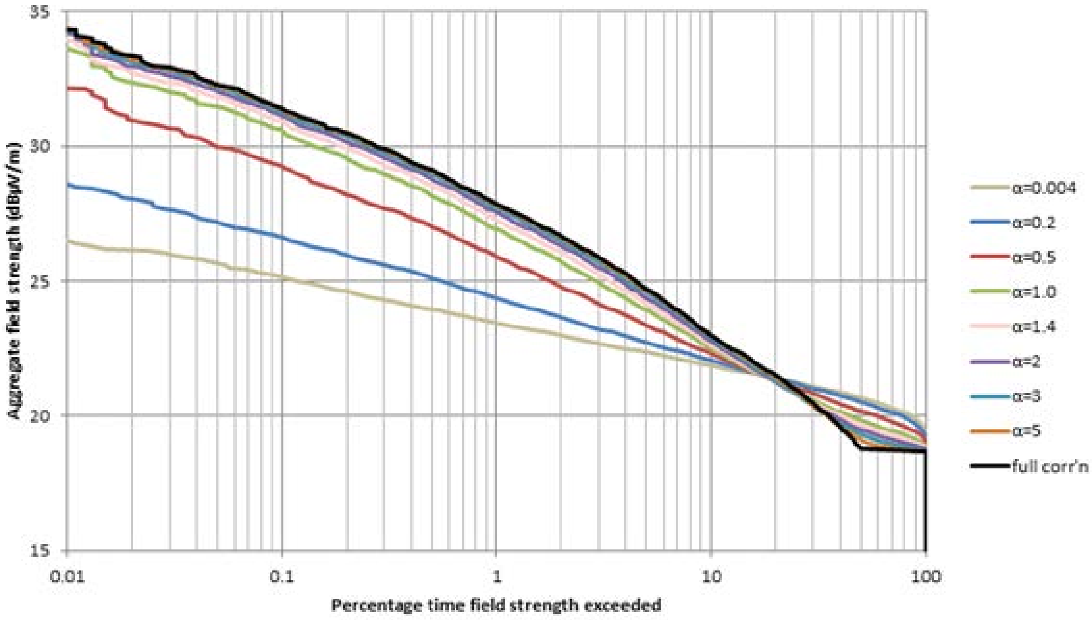


FIGURE 2.3

‘Shorter paths’ case

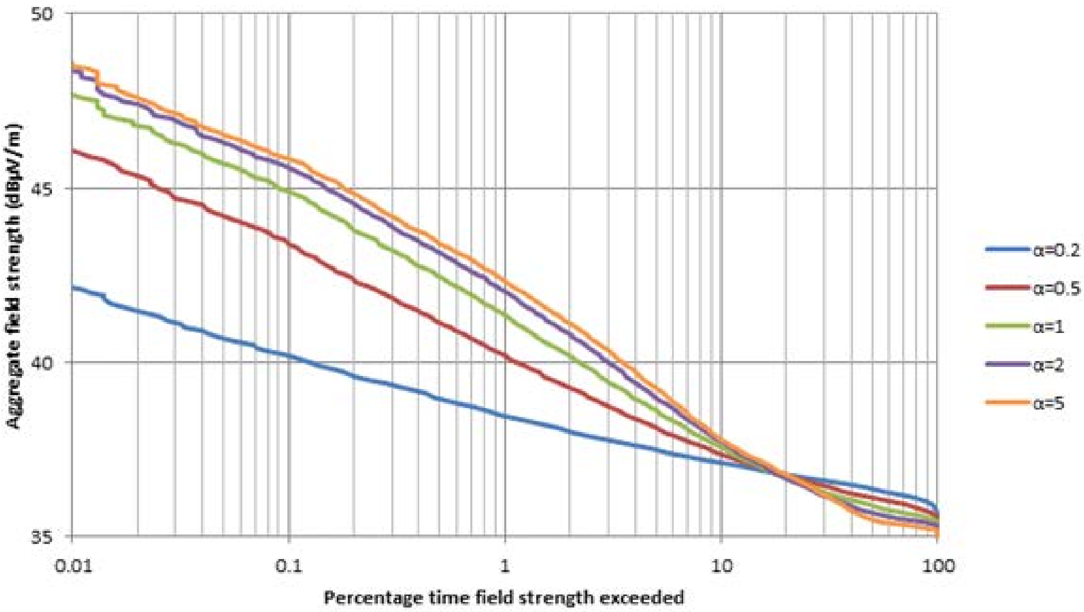
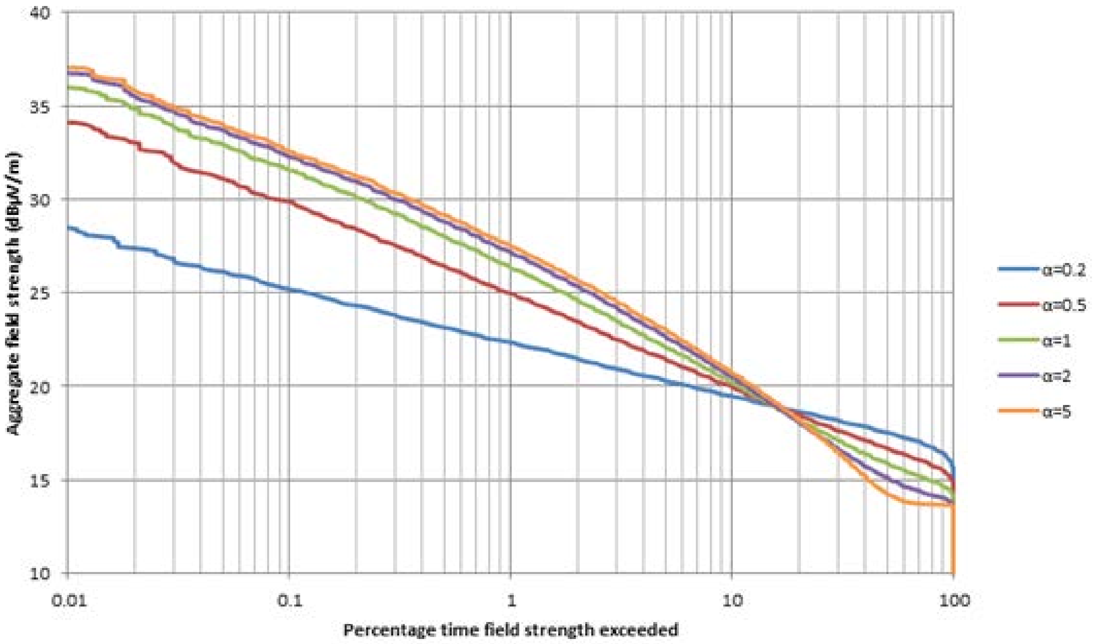


FIGURE 2.4

‘Large spread’ case



In the following figures, details of the above plots are reproduced, with additional data points representing the simple aggregate power sum from all transmitters, taken at fixed percentage-times (i.e. the fully-correlated assumption).

FIGURE 2.5

‘Longer paths’ case (detail)

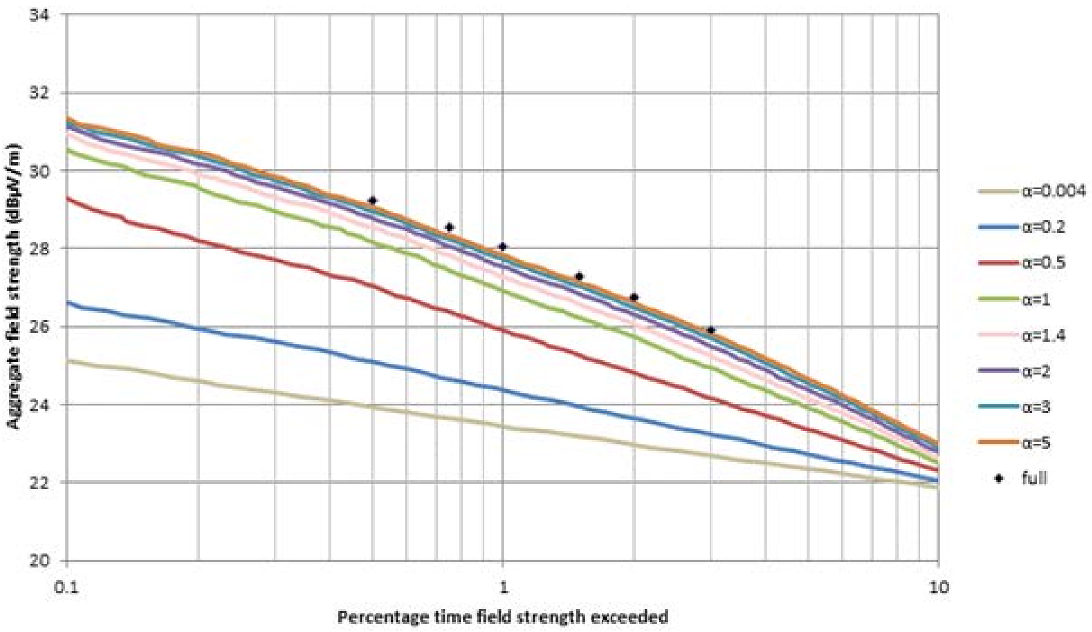


FIGURE 2.6

'Shorter paths' case (detail)

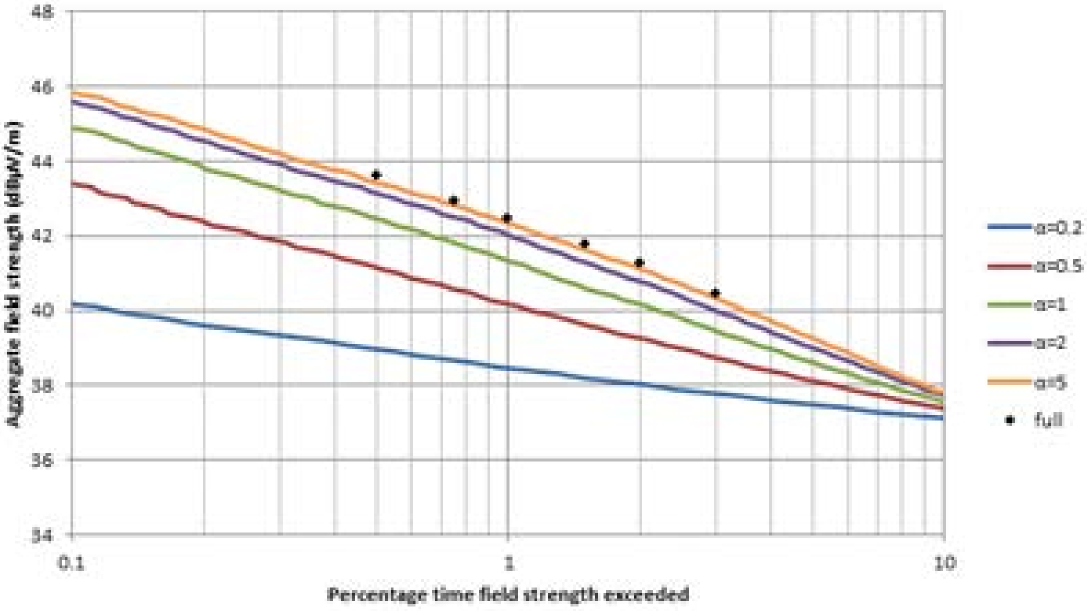
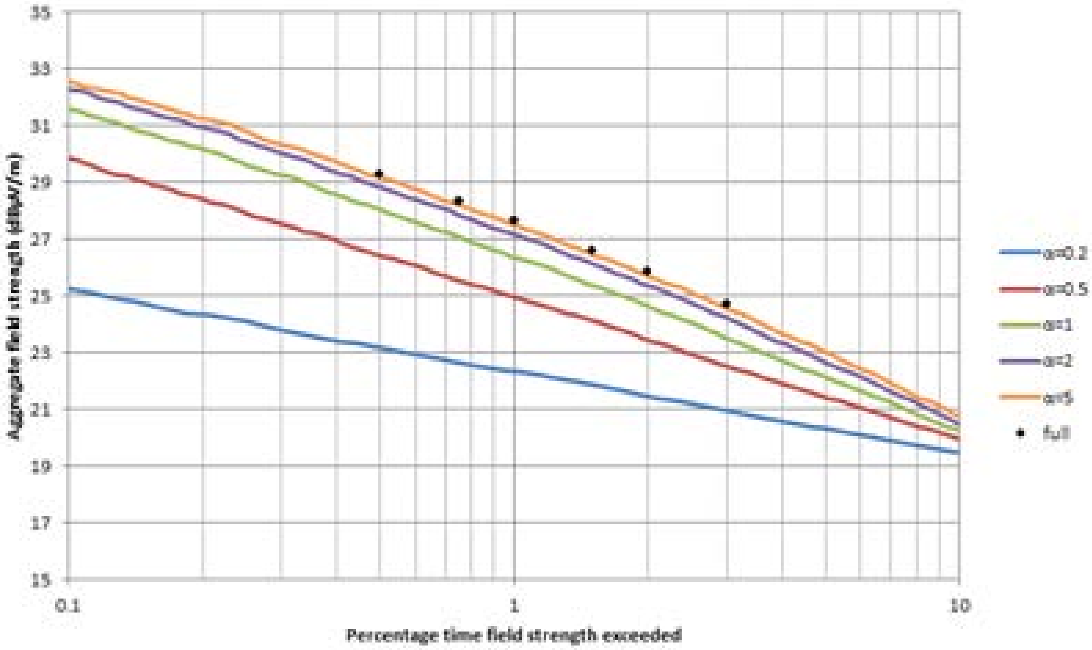


FIGURE 2.7

'Large spread' case (detail)



As would be expected, the new points are very close to the trace representing the highest value[3] of α.

TABLE 2.2

‘General method’ results

Scenario	Aggregate (full correlation)	Aggregate (General method,α=1.0)	Δwrt full correlation
‘Longer paths’	28.0dBμV/m	27.0dBμV/m	-1.1 dB
‘Shorter paths’	42.5dBμV/m	41.4dBμV/m	-1.1 dB
‘Large spread’	27.6dBμV/m	26.4dBμV/m	-1.3 dB

TABLE 2.3

‘Simple method’ results

Scenario	Aggregate (full correlation)	Aggregate (‘simple’ at 1.75%)	Δwrt full correlation
‘Longer paths’	28.0 dBμV/m	27.0dBμV/m	-1.0dB
‘Shorter paths’	42.5dBμV/m	41.5dBμV/m	-1.0 dB
‘Large spread’	27.6dBμV/m	26.2dBμV/m	-1.4 dB

If the ‘general method’ is used with α=1.0 (green trace), the ‘simple method’ gives the same field strength for a ‘corrected time’ of around 1.75%. This value is also supported by a contribution to CG 3K-4[4] - see Appendix B, below.

TABLE 2.4

Comparison of methods (corrected time=1.75%)

Scenario	General method, α=1.0	‘simple method’ corrected time = 1.75%	Δ (‘simple’ wrt ‘general’)
‘Longer paths’	27.0dBμV/m	27.0dBμV/m	+0.0 dB
‘Shorter paths’	41.4dBμV/m	41.5dBμV/m	+0.1 dB
‘Large spread’	26.4dBμV/m	26.2dBμV/m	-0.2 dB

[3] This value corresponds to a ‘correlation’ of 0.9.

[4] The contributions to CG 3K-4 are available at: https://extranet.itu.int/rsg-meetings/sg3/wp3k/cg3k4/default.aspx.

APPENDIX A

Basis of the 'General' method

This mathematically-rigorous method was proposed within Study Group 3 some time ago, although in a somewhat different context ("*Investigation of a new fixed-link planning method based on joint signal-level probability distributions*", Document 3M/159, 20 September 2006).

The problem is to estimate a joint probability distribution from two (or more) marginal CDFs given by a particular propagation model.

This linkage can be made by using the family of 'copula' functions, and a suitable candidate function has been found, empirically, to be the 'Clayton' copula. Further empirical comparison with data from a long-term measurement campaign in the UK has given a simple expression for correlation between paths of different lengths and relative azimuth, and hence for the 'Clayton parameter', α.

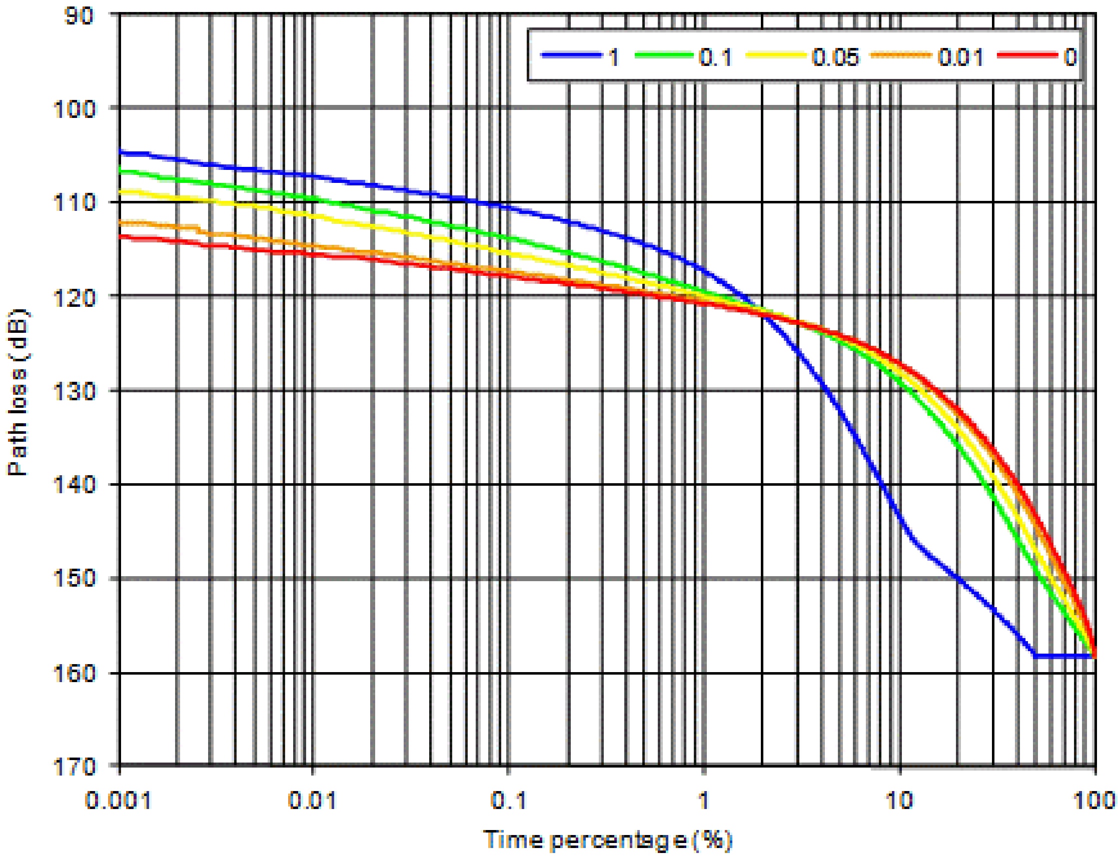
A submission to CG 3K-4[3] used copula functions within a Monte Carlo simulator to explore the impact of different assumptions about correlation on predictions of aggregate interference.

Figure A1 reproduces these results for aggregation over 42 paths, with each trace representing a different assumed correlation from zero to unity. It is seen that all correlation assumptions give the same aggregated power sum for a time percentage of ~2%, and consequently the spread of values at 1% is only ~3dB. The paper suggested that as this variation is small compared with the other variables in the problem it might be possible to ignore it and use the simple "power sum" assumption instead[5].

[5] Although the CG 3K-4 felt that the variation could not be ignored, the modest size of the effect relative to the overall uncertainty budget in interference predictions should be borne in mind.

FIGURE A1

Equivalent path loss for DTT interference from 42 paths



Although this contribution was making use of the method to illustrate a general point, it would seem entirely reasonable to propose that such a linkage of marginal CDFs by copulas might be used in the operational system-sharing models being developed by other ITU-R groups. As these are already intending to incorporate Monte Carlo modelling for the treatment of location variability, the additional computational overhead need not be great.

Another contribution[3] to CG 3K-4 describes how the method may be implemented, and this is briefly summarised below.

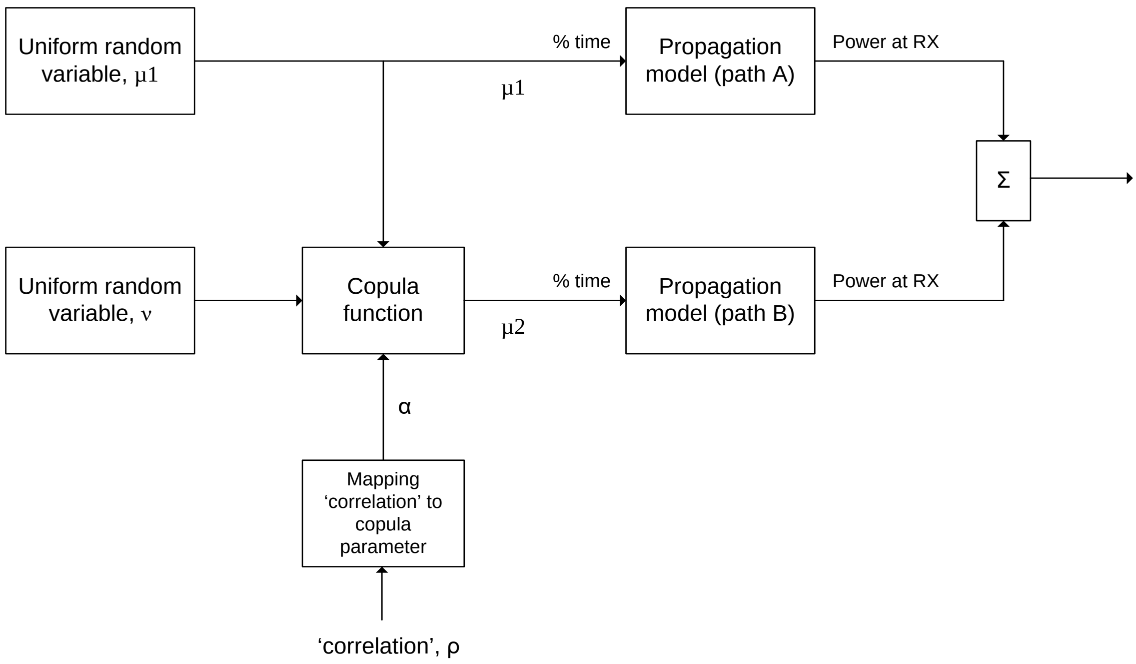
A.1 Implementation

For the case of interference aggregation from N sources, we are concerned, in principle, with an N-dimensional CDF rather than the 2-dimensional cases for which the method was originally developed (fading on a wanted link versus enhancements from a single interfering source). This is practically intractable, and attention has been focussed on a simplified case where one path is chosen as the 'reference' and only the N Correlations between this and the other paths are determined.

The figure below sketches the method by which a copula function may be used to derive a random variable µ2, having a specified correlation to a uniform random variable, µ1.

FIGURE A2

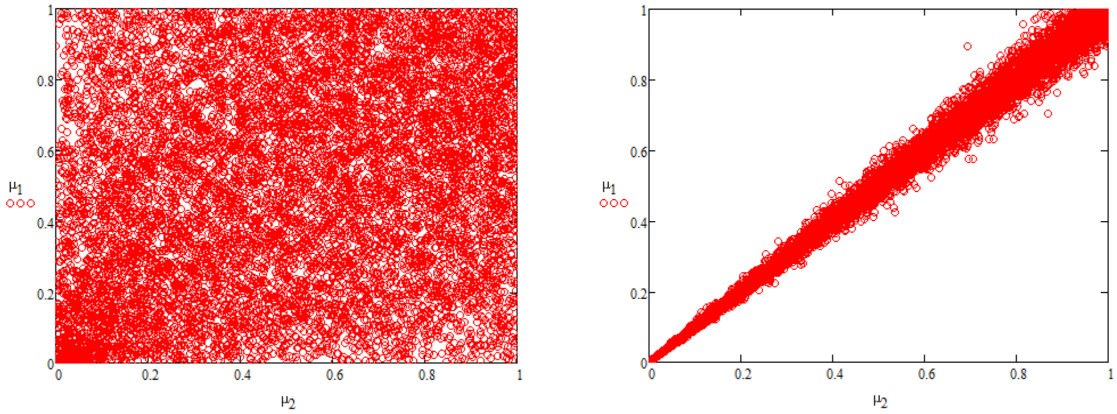
Generation of aggregate power statistics (2-path case)



Two uniform, independent variables of random numbers (μ1 and ν) are generated. One of these variables is used directly to sample the propagation model for one path. The other is used to generate a second random variable, conditional on the value of the first and on the required correlation between the two.

FIGURE A3

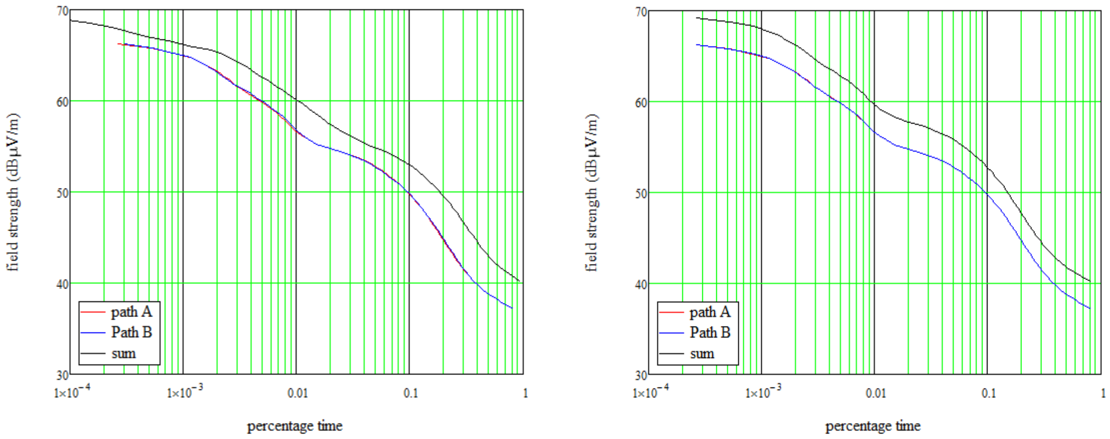
μ1 versus μ2 for correlation 0.2 (LHS) and 0.99 (RHS)



If the propagation models are now sampled using the two related random variables, the aggregate received power can be determined at each trial, and a 'CDF of the sums' developed. Figure A4 shows the output of the model for a simple case, using the same arbitrary, but plausible, propagation model[6] for each path.

FIGURE A4

Aggregate power for 'correlation' = 0.20 (LHS) and 0.99 (RHS)



The two-path case of the figures above can readily be extended for an arbitrary number of paths by using the copula to generate the required number of random variables on a pairwise basis with respect to a 'reference' uniform random variable.

Although the presentation in the form of a block diagram may seem slightly intimidating, the changes required to an existing Monte Carlo model, such as that of WP 6A, are rather minor. A mechanism for generating high-quality random numbers will already be present, and the copula function itself is computationally trivial.

The need to sample the pathloss CDFs adequately (perhaps by 1000 trials for results relating to a 1%-time criterion) is the main overhead, but it is noted in a contribution[3] to CG 3K-4 that this need not be done at each iteration; rather the loss CDF for a path can be pre-determined, and captured as a polynomial fit.

A.2 Choice of parameter

Of more concern is the choice of an appropriate 'copula parameter', α. The document notes that there is a simple relationship between this and correlation, ρ:

$$\alpha = \left(\frac{\rho}{1-\rho}\right)^{0.8}$$

but in the structure of Figure A2 this relates to the correlation between the variables representing probability (percentage time) rather than path loss. In practice, it will be the correlation in path loss that may be known from experiment, but this has a non-linear relationship (via the propagation model) with probability.

A contribution[3] to CG 3K-4 proposes that it is preferable to use the copula parameter directly, without attempting to relate this to formally-defined correlation in either probability or path-loss spaces. An

6 A simple linear spline fit to ten points on the field strength/%-time CDF.

empirical expression has been derived which links α with path characteristics that should, intuitively, affect the degree of ‘correlation’; angular separation, difference in path length and difference in transmit height.

This expression was derived by seeking the value of copula parameter giving the lowest RMS error between the predicted and measured joint statistics. The caveat is that the data used to obtain the fit was gathered from 12 trans-horizon land paths in eastern England operating at 1.4 GHz and 7.5 GHz – sea paths in particular may exhibit different behaviour.

Although the linkage between mutual path geometry and α is both intuitive and empirically-supported, it is not straightforward to apply in the multiple interferer case. Furthermore, given the relatively small impact of taking signal de-correlation into account in the first place, such refinements are unlikely to be justified by any significant increase in overall simulation accuracy.

It is therefore proposed that, for the purposes of modelling and simulation within WP 6A, a fixed value of α be used in all cases.

APPENDIX B

Basis of the 'Simple' method

The idea of allowing for the less-than-complete correlation of interfering signals by taking the power sum of signals predicted at an 'adjusted' or 'corrected' time was proposed to the CG 3K-4[3].

In this document, the required correction for different scenarios was tabulated on the basis of simulations; these were made using the simplifying assumption that interference from multiple sources is wholly uncorrelated at <10% time (and fully-correlated at ≥10% time). Values of between 2% and 3% were suggested, for situations where the 1%-time value is required.

It was also suggested that the correction could be made on a path-by-path basis (as a function of the number of interferers and of path-length, and hence temporal variability). A table given 'corrected time' values was given and is reproduced below.

TABLE B1

'Corrected-time' values (reproduced from Table 8 of CG Document A22)

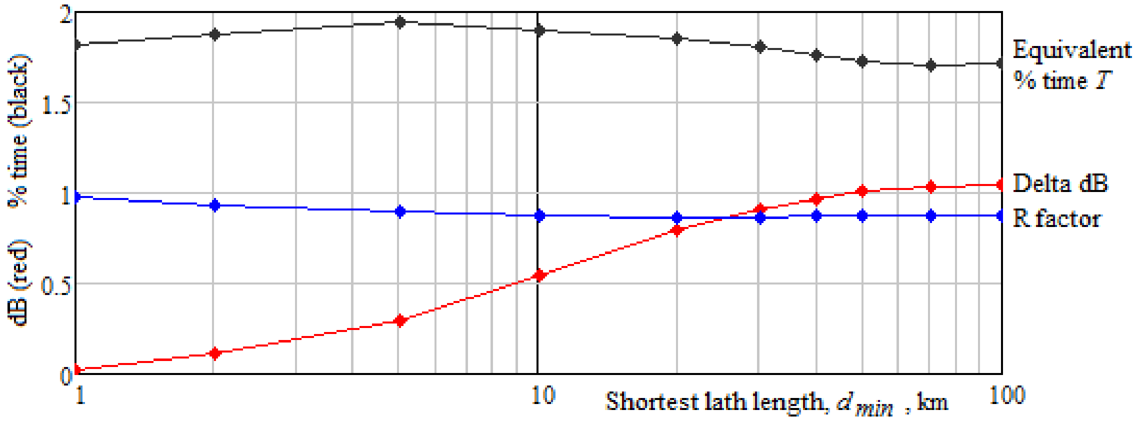
Number of interfering fields	Maximum propagation path length: D (for h_{eff} = 37.5 m)		
	D < 5 km (σ_t< 1 dB)	D < 17 km (σ_t< 3 dB)	D > 17 km (σ_t> 3 dB)
2	1.5%	1.4%	1.2%
5	2.1%	2.0%	1.5%
10	2.6%	2.2%	1.8%
20	2.9%	2.5%	2.1%
50	3.2%	2.8%	2.3%
100	3.4%	3.0%	2.5%
500	3.7%	3.2%	2.8%
1000	3.7%	3.3%	2.9%

The dependence of the required 'corrected time' on simulation parameters was further explored in a contribution to CG 3K-4[3], which also made use of extensive Monte Carlo simulations[7].

[7] Making the same 'uncorrelated at <10% time' assumption as in the contribution document.

FIGURE B1

Average dependence of 'corrected time' on path length (reproduced from CG 3K-4 contribution)



It appears from Figure B1 that formulating the 'corrected time' as a function of the shortest simulation path length would probably not be justified by any increase in accuracy.

The 'simple method' proposed in this document therefore applies a single 'corrected time' in all circumstances. The comparisons presented above (Table B1) suggest that this is an appropriate simplification.

The 'corrected time' value proposed, 1.75 %, has been determined by comparison with the 'general method' and the limited data available from the Ofcom long-term measurement campaign referenced above. It is expected that work to refine both this value and that of the copula parameter will continue within WP 3K; new data from the Netherlands, relating to sea-paths and mixed paths, is expected to be valuable in this regard.

APPENDIX C

Summary of work within CG 3K-4

Initial discussions within the group focussed on the empirical basis of models such as Recommendation ITU-R P.1546, the temporal and spatial characteristics of ducting and the evidence concerning correlation of fading and enhancements on different paths.

It was agreed that the empirical evidence for joint-path statistics is very limited, with only three directly-relevant sets of measurements having been identified:

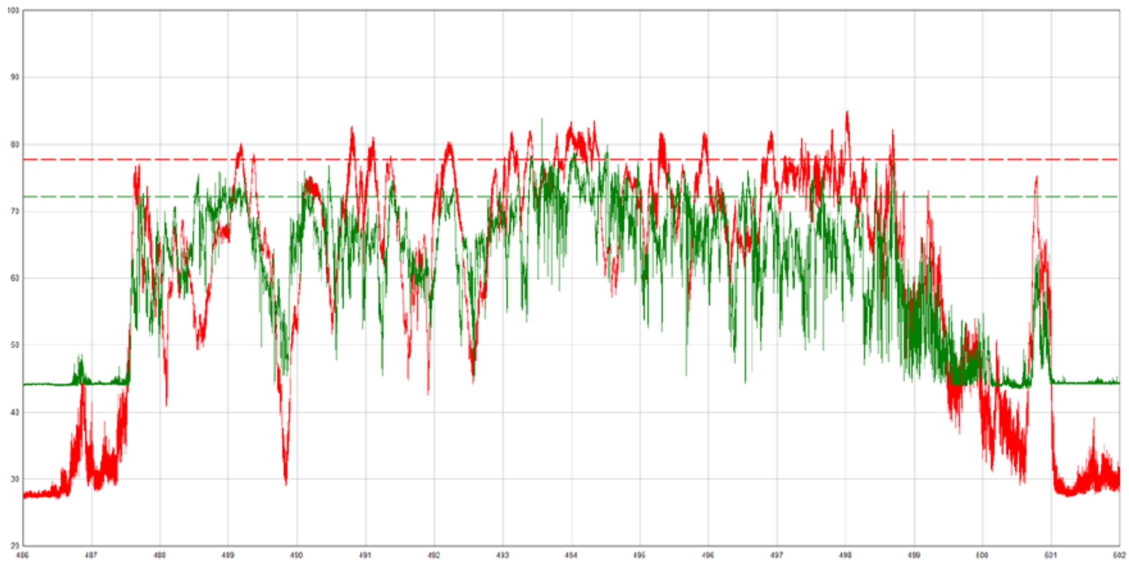
- A very comprehensive set of measurements on seven land-paths in Eastern England at 1.4 GHz (and higher frequencies). This campaign by Ofcom was explicitly intended to gather data on joint path statistics and is referred to as the LTMC (long-term measurement campaign).
- A set of measurement made of aggregate (single frequency network) and individual field strengths arriving at two coastal locations in the UK from France and the Netherlands. These measurements were not intended to gather joint statistics and can offer only anecdotal information on this.
- Measurements made of mixed land-sea paths from TV transmitters in the Netherlands, recorded at three sites in the Netherlands and UK for more than a year. Although not intended to gather joint statistics, it has been found possible to re-examine the records to derive information of the correlation of signals from different sites. There is some suggestion that a greater degree of correlation may be present on sea paths than on comparable land path, although formal analysis of the data has not yet been possible.

Examining the records from these campaigns showed that there was generally a very strong correlation between incidences of ducting on different paths across quite a wide area. This reflects the underlying meteorological causes of such ducting. What was also clear, however, was that the rapid fading of ducted signals was significantly less closely correlated.

This is seen in Figure C.1 below, which shows the signals received over a period of 16 days at a coastal location in the UK from transmitters in the Netherlands (green trace) and Belgium (red trace). Although ducting on both paths is established at exactly the same time (mid-way through day 487), the fine detail of the fading within the duct is less strongly correlated.

FIGURE C.1

North sea ducting event with 1% field levels indicated



This observation formed the basis for modelling by several members of the CG in which the following simplifying assumptions were made:

- Pathloss temporal variation is fully correlated at ≤10% time.
- Pathloss temporal variation is un-correlated at >10% time.

Using this approximation to represent ‘real’ signal behaviour, Monte Carlo simulations were then carried out to examine the relative accuracy of different modelling options; these included the use of corrections in time or amplitude which might be functions of path length and the number of interferers involved in the simulations. One proposal applied a correction in amplitude that was based on the ratio of the highest individual interferer power to the aggregate power sum of all interferers. An issue with the corrections in amplitude was the need to ensure appropriate behaviour as the interference path length tends to arbitrarily small values.

A rather different approach, based on a rigorous mathematical analysis and simplified for the present case was also proposed. This method, using so-called copula functions had been validated using data from the LTMC measurements described above.

In the course of the many simulations undertaken, and the analysis of the limited measurement data available, it was clear that the effect to be modelled is rather small in the context of the other uncertainties that are inevitable in sharing studies. In most cases the correction required at 1% to allow for less than full correlation of interference is less than 2 dB.

The options available to the group therefore ranged from very simple empirical corrections, through a number of proposals that made the necessary correction a function (tabulated or continuous) of various path or simulation parameters, to the potentially rigorous (though simplified for the present application) approach using Copulas.

As the copula method appears to be robust (i.e. the results behave ‘sensibly’ for all simulation scenarios, path lengths, etc.), is rigorously founded and based on empirical data, it was preferred by some members of the group.

On the other hand, the copula method requires significant computation and, given the relatively small nature of the correction required, may not always be justified. The very simple approach of correction based on a percentage-time offset was therefore also considered.

Other methods that had been proposed offered neither the extreme simplicity of the 'time-offset' approach, nor the empirical[8] and formal validity of the 'copula' approach.

Towards the end of the work of the Correspondence Group, the a number of computational issues were raised, the most significant of these relating to the number of iterations required to achieve convergence of results in a Monte Carlo model (whether for location or temporal variability, or both). This is a topic that clearly merits further study, but in the interests of producing timely advice to WP 6A, the CG 3K-4 has not delayed reporting to investigate this issue. The group can only stress that care must be taken to ensure that any results generated by such models should be carefully checked to ensure that the confidence intervals are appropriate to the task in hand.

[8] It must again be emphasised that there is very little empirical data available regarding joint path statistics, and consequently all methods and associated parameters are tentative.

3GPP TSG RAN WG1 Meeting #97 R1-1906634

Reno, USA 13th May – 17th May 2019

Agenda item: **6.2.4.2**

Source: EBU, BBC, IRT

Title: Network Simulations Incorporating Time Variation for the CAS

Document for: Discussion

1. Introduction

During the RAN WG1 96-bis meeting in April it was agreed in [1] that:

"For the evaluation of CAS, RAN1 adopts a methodology related to the pathloss model that considers the following:

- *Cell reselection procedure (i.e., the UE may select the serving cell depending on the actual pathloss)*
- *The pathloss may not be constant for a given location"*

In pursuit of the above, [2] suggested that Monte Carlo simulations should be carried out in the time domain (as well as in the spatial domain), and set out a methodology for doing so based on a procedure set out in ITU document 6A/198-E [3] from working party 3K (submitted to RAN1 #96-Bis as R1-1905331 and discussed during the meeting). The General method in the ITU document outlines a process for modelling time varying field strengths from multiple transmitters for which the degree of correlation between signals, as they vary over time, may be defined.

In order to further inform the performance requirements for the CAS, this document presents the results of network simulations incorporating time variation based on the General method for a number of different network configurations and receiving environments.

2. Background

2.1 ITU 3K General Method

Measurements of the signal levels from multiple transmitters received at a static location indicate that the received signal levels vary in time, and that the variations of one signal compared with another have a degree of correlation. The ITU 3K General method in [3] outlines a method for modelling time-variable signals from multiple transmitters in Monte Carlo simulations. The method allows the time variation correlation of one signal with another to be incorporated with the Clayton copula function.

Page 3 of [3] provides pseudo code for the General method which sets out how to generate vectors of correlated time varying signals. As the original context of the 3K work was to calculate the power sum of multiple signals, the pseudo code has been modified slightly for the purposes of this work in which we need to generate vectors of the instantaneous field strength levels for all the transmitters in the network so that the UE's cell (re)selection procedure may be taken into account in the case of a single cell CAS configuration, and to more accurately model MBSFN. The modified pseudo code is shown below. It is incorporated into the wider Monte Carlo time variation algorithm set out further below.

In all cases the value of α (the factor setting the correlation between signal levels over time) has been set to 1, as suggested in [3].

Pseudo Code for Time-Correlated Signal Generation

FOR *time_trial_index* = 0…*M*
{
    get initial RV, µ1, from uniform distribution in range [0, 1]
    FOR *n* = 1…*N*
    {
        get RV, ν, from uniform distribution in range [0, 1]
        derive new RV,

$$\mu_2 = \mu_1\left(v^{-\alpha/(\alpha+1)} - 1 + \mu_1^{\alpha}\right)^{-1/\alpha}$$

        store μ_2 in vector at μ_2*(n,time_trial_index)*
    }
}

Pseudo Code for Align Receiving Antenna to the Strongest Signal After Shadow Fading

1 Generate µ2(N,M) for N transmitters and M = 10,000+ time instances
2 For location from 1 to 10,000+
3 Compute Field Strengths, FS, for N by M matrix based on location and µ2 using P1546 with probability = µ2*100
4 Compute 50% time Field Strength,FS50, for N transmitters using P1546 with probability = 50
5 Generate N shadowing gains and add to N by M FS matrix
6 Align Rx antenna to max(FS50) and adjust FS matrix
7 For each time instance
8 Get N element vector of field strengths from FS for this time instance, $FS_{thistimeinstance}$
9 Position FFT window on $FS_{thistimeinstance}$ and adjust values according to weighting function
10 Compute SINR of $FS_{thistimeinstance}$ and store in vector of $SINR_{time}$
11 Next time
12 Retain 99th percentile of SNR_{time} in vector $SNR_{time\_location}$
13 Next location
14 Output the 99th percentile of $SNR_{time\_location}$

It is assumed in line 1 of the second block of pseudo code that the time fading statistics are constant across the entire coverage area i.e. they are 100% correlated in space for a given instance in time.

Lines 5 and 6 are interchanged in order to effect the Align Receiving Antenna to the Strongest Before Shadowing Algorithm.

In the case of single cell operation, either full single cell, or a mixture of single cell and SFN, a different method is applied at line 9. The wanted signal is defined as Max($FS_{thistimeinstance}$). The FFT window is then positioned according to the chosen strategy based on the signals that are in the same MBSFN as the wanted transmitter. All other signals become interferers and the SINR is computed. Note that this procedure could be sub-optimal in some instances where the strongest signal is not in the same MBSFN area as that which would provide maximum energy in the CP and EI.

The cell re/selection procedure is effectively carried out in line 9 of the second block of pseudo code, and only applies to networks comprising some element of single cell. For MBSFN cell reselection is replaced by the FFT window positioning strategy.

2.2 Simulation Parameters

Simulations for car mounted and fixed rooftop reception have been carried out according to the framework set out in [4] and the additional parameters below.

Parameter	Value	Comment
Receiver synchronisation	Strongest signal in time and location	Reflects cell reselection
Time variation	General method	Based on [3], modified according to S2.1 above
FFT Window Positioning Strategy	First signal above threshold Strongest signal Maximum energy window	Described in [5]
Cyclic Prefix	16.7 µs	
Equalisation Interval	22 µs	RS separation of 3 in the frequency domain
Coverage Target	99th percentile random dropping throughout entire network coverage area	Motivated in [6]
CAS Network Configuration	Single Cell - Three independent sectors per site Single Cell – All three sectors in SFN at each Site SFN – All sectors and all sites in SFN	Described in [5]
Receiving Antenna Alignment	a) Strongest transmitter before location variation b) Strongest transmitter after location variation	a) To accommodate legacy deployments b) to accommodate new deployments (greenfield)

Table 1: Additional Simulation Parameters for Clarification.

2.3 Performance Requirements for the CAS Constituent Channels

The RAN4 performance requirements identified in [4] for the constituent channels of the CAS are shown in table 2. They have been used to assess whether the CAS would meet the achievable SINR from the network simulations.

Reception Environment		PDCCH	PBCH	PDSCH	PSS/SSS
Car Mounted	1T2R	-1.7	-6.1	-5.4	?
Fixed Rooftop	1T1R*	1.3	-3.1	-2.4	?

Table 2: RAN4 Performance Requirements for Constituent CAS Channels (dB)

The RAN4 performance requirements in TR 36.101 are for at least 2 Rx antennas (2R) and, in some cases, with 2 Tx antennas (2T), hence performance for the relevant fixed rooftop channel with 1 Tx and 1 Rx antenna can only be implied – they have been set to be 3dB higher than those for 1T2R.

3. CAS Car Mounted

In this section the CAS is investigated for the car mounted scenario. Throughout this section, as the receiving antenna is omni-directional, the wanted signal has been defined as the strongest signal after location variation.

3.1 Single Cell

Table 3 shows the SINR achievable for the 99th percentile for single cell scenarios aimed at car mounted reception. The table also shows the difference between the appropriate SINR performance requirement from section 2.3 and the achievable SINR in the network. The difference has been called the margin and is positive when the performance requirement exceeds the achievable SINR in the network. In order to quickly summarise the results a RAG analysis has been carried out where negative margins are highlighted red and margins < 1dB are amber. The red and amber highlighted cells indicate which sub-channels of the CAS may need to be made more robust.

Network Topology	Tx Antenna	FFT Synchronisation Strategy	99th percentile Random Dropping	CAS Component Channel Margin vs General Method Results			
				PDCCH	PBCH	PDSCH	P/SSS
LPLT 3 Sector SFN	Sectorised	1st above a threshold	-5.1	-3.4	1	0.3	
LPLT 3 Sector SFN	Sectorised	Strongest	-5.1	-3.4	1	0.3	
LPLT 3 Sector SFN	Sectorised	Max energy window	-5.1	-3.4	1	0.3	
LPLT 3 Independent Sectors	Sectorised	N/A	-5.6	-3.9	0.5	-0.2	
MPMT	Omni	N/A	-4.1	-2.4	2	1.3	
HPHT1	Omni	N/A	-3.9	-2.2	2.2	1.5	

Table 3: Achievable SINR (dB) for car mounted single cell.

Observation 1: The current performance requirements for the PDCCH and PDSCH would not be sufficient to fulfil the Single Cell Car Mounted use case. In order to fulfil this use case the PDCCH and PDSCH would have to be made at least 3.9dB and 0.2dB more robust, respectively.

3.2 SFN

Table 4 shows the results for the CAS where all transmitters in the network operate in an SFN (16µs CP, 22µs EI). Three different FFT window positioning strategies have been investigated. A RAG analysis has again been carried out.

FFT Window Positioning Strategy	Network Topology	Tx Antenna	99th percentile Random Drops	CAS Component Channel Margin vs General Method Results			
				PDCCH	PBCH	PDSCH	P/SSS
1st above a threshold	LPLT	Sectorised	-1.7	0	4.4	3.7	
	MPMT	Omni	-10.4	-8.7	-4.3	-5	
	HPHT1	Omni	-15.8	-14.1	-9.7	-10.4	
Strongest signal	LPLT	Sectorised	-4.0	-2.3	2.1	1.4	
	MPMT	Omni	-3.7	-2	2.4	1.7	
	HPHT1	Omni	-3.6	-1.9	2.5	1.8	
Maximum energy	LPLT	Sectorised	-1.9	-0.2	4.2	3.5	
	MPMT	Omni	-3.1	-1.4	3	2.3	
	HPHT1	Omni	-3.3	-1.6	2.8	2.1	

Table 4: Achievable SINR (dB) for car mounted reception in SFN

The following observations have been made based on the results in table 4.

Observation 2: The maximum energy FFT window positioning strategy is the most efficient for car mounted SFN. It should be ensured that all UE's operate with this algorithm or better.

Observation 3: The current performance requirements for the PDCCH would not be sufficient to fulfil the MPMT SFN Car Mounted use case. In order to fulfil this use case the PDCCH would have to be made at least 1.4dB more robust, to give an absolute performance of -3.1dB or better.

4. Fixed Rooftop

[7] sets out that it is desirable to avoid the need to realign receiving antennas in situations where they already exist. The strongest transmitter before location variation method is therefore best suited for modelling these situations. When there is no installed base of receiving antennas (greenfield) the strongest transmitter after location variation methodology may be more suitable. Results for both methodologies have therefore been presented below.

4.1 Single Cell

Table 5 shows the achievable SINR for the 99th percentile for a number of single cell scenarios aimed at fixed rooftop reception. As can be seen from the table, the achievable SINR is, again, sensitive receiving antenna alignment algorithm.

Although the most onerous case for single cell fixed rooftop reception would be LPLT with three independent sectors and receiving antenna alignment before location variation, this use case may not need further consideration as there are unlikely to be any legacy networks for which support for this mode will be required.

The most critical case therefore appears to be the LPLT three independent sectors case in which receiving antennas are aligned to the strongest signal after location variation. In order to support this use case the PDCCH should be made at least 1.7 dB more robust.

Rx Antenna Alignment	Network Topology	Tx Antenna	FFT Synchronisation Strategy	99th Percentile Random Drops	CAS Component Channel Margin vs General Method Results			
					PDCCH	PBCH	PDSCH	P/SSS
Strongest b. LV	LPLT 3 Sector SFN	Sectorised	1st above a threshold	-0.5	-1.8	2.6	1.9	
Strongest b. LV	LPLT 3 Sector SFN	Sectorised	Strongest	-0.6	-1.9	2.5	1.8	
Strongest b. LV	LPLT 3 Sector SFN	Sectorised	Max energy window	-0.4	-1.7	2.7	2.0	
Strongest b. LV	LPLT 3 Ind Sectors	Sectorised	N/A	-2.1	-3.4	1	0.3	
Strongest b. LV	MPMT	Omni	N/A	-0.2	-1.5	2.9	2.2	
Strongest b. LV	HPHT1	Omni	N/A	0.1	-1.2	3.2	2.5	
Strongest a. LV	LPLT 3 Sector SFN	Sectorised	1st above a threshold	5.7	4.4	8.8	8.1	
Strongest a. LV	LPLT 3 Sector SFN	Sectorised	Strongest	5.2	3.9	8.3	7.6	
Strongest a. LV	LPLT 3 Sector SFN	Sectorised	Max energy window	5.4	3.7	8.5	7.7	
Strongest a. LV	LPLT 3 Ind. Sectors	Sectorised	N/A	-0.4	-1.7	2.7	2	
Strongest a. LV	MPMT	Omni	N/A	6.3	5	9.4	8.7	
Strongest a. LV	HPHT1	Omni	N/A	6.8	5.5	9.9	9.2	

Table 5: Achievable SINR (dB) for single cell, fixed rooftop reception

Observation 4: The current performance requirements for the PDCCH would not be sufficient to fulfil the LPLT three independent sectors for fixed rooftop reception use case. In order to fulfil this use case the PDCCH would have to be made at least 1.7dB more robust, to give an absolute performance of -0.4dB or better.

4.3 SFN

Table 6 shows the SINR achievable for the 95th and 99th percentile for a number of scenarios aimed at fixed rooftop reception in CAS SFN (16µs CP, 22µs EI). As can be seen from the table, for each type of network the achievable SINR is again sensitive to the time-model that is used, the receiving antenna alignment methodology and the FFT window positioning strategy.

Table 6 shows that the maximum energy FFT window positioning strategy provides the best results. It is therefore recommended that UEs operate with this strategy or better.

Under the assumption that the maximum energy window strategy is used, the final six rows of table 6 are of interest. They show that in order to support fixed rooftop reception in legacy HPHT1 networks the CAS would have to be made at least 0.5 dB more robust.

Rx Antenna Alignment	FFT Synchronisation Strategy	Network Topology	Tx Antenna	99th percentile Random Drops	CAS Component Channel Margin vs General Method Results			
					PDCCH	PBCH	PDSCH	P/SSS
Strongest b. LV	1st above a threshold	LPLT	Sectorised	2.7	1.4	5.8	5.1	
Strongest b. LV	1st above a threshold	MPMT	Omni	2.3	1	5.4	4.7	
Strongest b. LV	1st above a threshold	HPHT1	Omni	1.0	-0.3	4.1	3.4	
Strongest a. LV	1st above a threshold	LPLT	Sectorised	3.8	2.5	6.9	6.2	
Strongest a. LV	1st above a threshold	MPMT	Omni	-25.4	-26.7	-22.3	-23	
Strongest a. LV	1st above a threshold	HPHT1	Omni	-30.7	-32	-27.6	-28.3	
Strongest b. LV	Strongest	LPLT	Sectorised	0.3	-1	3.4	2.7	
Strongest b. LV	Strongest	MPMT	Omni	0.9	-0.4	4	3.3	
Strongest b. LV	Strongest	HPHT1	Omni	0.4	-0.9	3.5	2.8	
Strongest a. LV	Strongest	LPLT	Sectorised	5.5	4.2	8.6	7.9	
Strongest a. LV	Strongest	MPMT	Omni	6.6	5.3	9.7	9	
Strongest a. LV	Strongest	HPHT1	Omni	7.3	6	10.4	9.7	
Strongest b. LV	Max energy window	LPLT	Sectorised	2.8	1.5	5.9	5.2	
Strongest b. LV	Max energy window	MPMT	Omni	2.2	0.9	5.3	4.6	
Strongest b. LV	Max energy window	HPHT1	Omni	0.8	-0.5	3.9	3.2	
Strongest a. LV	Max energy window	LPLT	Sectorised	5.6	4.3	8.7	8.0	
Strongest a. LV	Max energy window	MPMT	Omni	6.7	5.4	9.8	9.1	
Strongest a. LV	Max energy window	HPHT1	Omni	7.3	6	10.4	9.7	

Table 6: Achievable SINR (dB) for CAS SFN, fixed rooftop reception

Observation 5: The maximum energy FFT window positioning strategy is the most efficient for fixed rooftop SFN. It should be ensured that all UE's operate with this algorithm or better.

Observation 6: The current performance requirements for the PDCCH would not be sufficient for SFN fixed rooftop HPHT1 existing network scenarios. In order to fulfil this use case the PDCCH would have to be made at least 0.5dB more robust to provide an absolute performance requirement of 0.8dB.

6. Summary

Observations 2 and 5 are as follows:

Observation 2: The maximum energy FFT window positioning strategy is the most efficient for car mounted SFN. It should be ensured that all UE's operate with this algorithm or better.

Observation 5: The maximum energy FFT window positioning strategy is the most efficient for fixed rooftop SFN. It should be ensured that all UE's operate with this algorithm or better.

Based on these two observations the recommendation 1 is made.

Recommendation 1: The UE FFT positioning strategy should be standardised to ensure that the maximum energy falls within the CP (or better, if another algorithm is found to be practical and superior).

Based on recommendation 1, hexagonal grid simulations, the framework set out by 3GPP, and a performance criterion of the 99th percentile 'random drops' throughout the entire coverage area, observations 1, 3, 4 and 6 have been summarised in the table below which sets out the improvement that would need to be made to the PDCCH and PDSCH (the other channels appear adequately robust).

Reception Mode	Network	PDCCH		PDSCH	
		Relative Improvement	Absolute Performance	Relative Improvement	Absolute Performance
Car Mounted	LPLT – Single Cell (3 Independent Sectors)	3.9	-5.6	0.2	-5.6
Car Mounted	MPMT Full SFN	1.4	-3.1	-	-
Fixed	MPMT Single Cell Legacy Network	1.5	-0.2	-	-
Fixed	LPLT Single Cell 3 independent sectors Greenfield	1.7	-0.4	-	-
Fixed	HPHT SFN Legacy Network	0.5	0.8	-	-

Table 7: Summary of the performance requirements and improvements needed for the CAS (dB)

The most onerous case for 1T2R in table 7 is car mounted in a single cell LPLT network with three independent sectors. The constituent channels of the CAS should be made robust enough to support this use case.

Recommendation 2: All the channels in the CAS, particularly the PDCCH and PDSCH, should operate down to at least -5.6dB SINR with 1T2R in the appropriate channel for car mounted reception in single cell LPLT networks with three independent sectors.

The most onerous case for 1T1R in table 7 is fixed rooftop reception in LPLT single cell greenfield network. The constituent channels of the CAS should be made robust enough to support this use case.

Recommendation 3: All the channels in the CAS, particularly the PDCCH, should operate down to at least -0.4dB SINR with 1T1R in the appropriate channel for fixed rooftop reception in greenfield LPLT single cell networks with three independent sectors.

References

[1]. R1-1905569; Chairman's notes of AI 6.2.4 LTE-based 5G Terrestrial Broadcast; 3GPP RAN WG1 #96; Xi'An, China, April 2019

[2]. R1-1904535; "Analysis of CAS reception"; Qualcomm Inc.; 3GPP RAN WG1 #96; Xi'An, China, April 2019

[3]. 6A/198-E; "Liaison statement to Working Party 6a, Report on the work of correspondence group 3K-4 concerning the correlation of short term interfering signals"; ITU, March 2013

[4]. 3GPP TR 36.776; "Study on LTE-based 5G terrestrial broadcast (Release 16)"; 3GPP; March 2019

[5]. R1-1810319; "Network Simulations Regarding the Performance of the CAS"; EBU, BBC, IRT; 3GPP RAN 3GPP RAN WG1 #96; Xi'An, China, April 2019

[6]. R1-1810319; "Public service broadcaster requirements and background information relevant to LTE-based 5G Terrestrial Broadcast"; EBU, BBC, IRT; 3GPP RAN WG1 #94-bis, Chengdu, China; October 2018

[7]. R1-1812430; "Evaluation Results for LTE-Based 5G Terrestrial Broadcast"; EBU, BBC, IRT; 3GPP RAN WG1 #95; Spokane; USA, November 2018

Acknowledgements

This work was supported in part by the European Commission under the 5G-PPP project Broadcast and Multicast Communication Enablers for the Fifth-Generation of Wireless Systems 5G-XCast (H2020-ICT-2016-2 call, grant number 761498). The views expressed in this contribution are those of the authors and do not necessarily represent the project.

3GPP TSG RAN WG1 Meeting #97 **R1-1907093**

Reno, USA 13th May – 17th May 2019

Agenda item: **6.2.4.1**

Source: EBU, BBC, IRT

Title: Spectral Efficiency of New Numerologies for Rooftop Reception

Document for: Discussion

1. Introduction

Potential new numerologies to support fixed rooftop reception in MPMT and HPHT1 networks were set out in [1]. The numerologies had been identified based on their ability to align with the frame structure of the CAS in MBMS-dedicated carriers and the frame structure of mixed carriers. They have therefore gone through the first down-selection step. It was then agreed in [2] to further progress the down-selection of these numerologies based on the outcome of further system and link level simulations as well as UE complexity considerations.

This document provides network simulation results for fixed rooftop reception for a subset of the numerologies in [1] in order to inform the next steps in the down-selection process.

2. Background

2.1 Numerologies for Further Down-Selection

The numerologies identified in [1] for further down selection set out below in table 1. In [2] it was agreed to consider only those numerologies with factors of 2 and/or 3. The numerologies that do not meet this criterion have been greyed out below, and have not been considered any further.

System level simulations have therefore been carried out for numerologies with ID 1, 2, 6 and 8 in order to determine their relative spectral efficiencies (SEs) and to further inform the down-selection process.

ID	T_{cp} (us)	T_u (ms)	T (ms)	Numerology (kHz)	FFT size	Number of MBSFN subframes per 40ms in MBMS-dedicated carrier (with no gap overhead)	Number of MBSFN subframes per 5ms (with gap overhead in mixed-carrier)	CP overhead
1	386	2.4	2.786	0.417	36846	14	1 (4.3%)	13.9%
2	300	2.7	3	0.370	41472	13	1 (0%)	10.0%
3	400	2.6	3	0.385	39936	13	1 (0%)	13.3%
4	300	2.95	3.25	0.339	45312	12	1 (15.0%)	9.2%
5	400	2.85	3.25	0.351	43776	12	1 (15.0%)	12.3%
6	345	3.2	3.545	0.313	49152	11	1 (9.1%)	9.7%
7	445	3.1	3.545	0.323	47616	11	1 (9.1%)	12.6%
8	300	3.6	3.9	0.278	55296	10	1 (2.0%)	7.7%
9	400	3.5	3.9	0.286	53760	10	1 (2.0%)	10.3%

Table 1: Numerologies for down selection with FFT factors other than 2 and/or 3 greyed out

2.2 Simulation Parameters

The simulations for this document have been carried out with two different methodologies:

a) The SINR has been computed with random dropping in a small area at the apex of the central hexagon, as described in section 5 of [3]. The 95th percentile of the SINR complementary CDF has been reported.

b) The SINR has been computed with random dropping over the entire coverage area. The 99th percentile of the complementary CDF has been reported.

In both cases the 50/1 (wanted/interferer) time model has been used. Furthermore, perfect EVM has also been assumed as it may be considered to be a matter of implementation, particularly in the case of MPMT and HPHT transmitters. In both cases the receiving antenna has been aligned to the strongest transmitter before location variation has been applied (also equivalent to the closest transmitter). All other parameters are aligned with [4].

2.3 Derivation of Spectral Efficiency

The spectral efficiency in this document has been calculated using the unconstrained Shannon capacity in conjunction with the CP overheads as shown by expression (1). It has been assumed that all modes have the same overheads in all other areas such as the reference symbol patterns. The SINR has been obtained from the simulations in this document.

$$SE = \log_2(1+SINR_{Linear}) * (1-CP_{Overhead}/100) \qquad (1)$$

2.3 Naming Convention

In the text below we refer to numerologies using the convention of CP/T_U/EI where CP is the cyclic prefix duration, T_U is the useful symbol duration, and EI is the equalisation interval duration. All durations have units of microseconds.

3. Simulation Results - Fixed Rooftop Reception

3.1 MPMT

The complementary CDFs of the SINRs and SEs for MPMT fixed rooftop are shown below in figure 1 for methodology a) and in figure 2 for methodology b). The corresponding SEs for both methodologies are set out at the relevant percentiles in table 2.

From table 2 it can be seen that the SEs are broadly similar for all the numerologies across both methodologies a) and b). However, methodologies a) and b) both show that numerologies 6 and 8 have marginally higher SE than the remaining two.

Observation 1: Numerologies 6 and 8 may be the best candidates for fixed rooftop reception in MPMT.

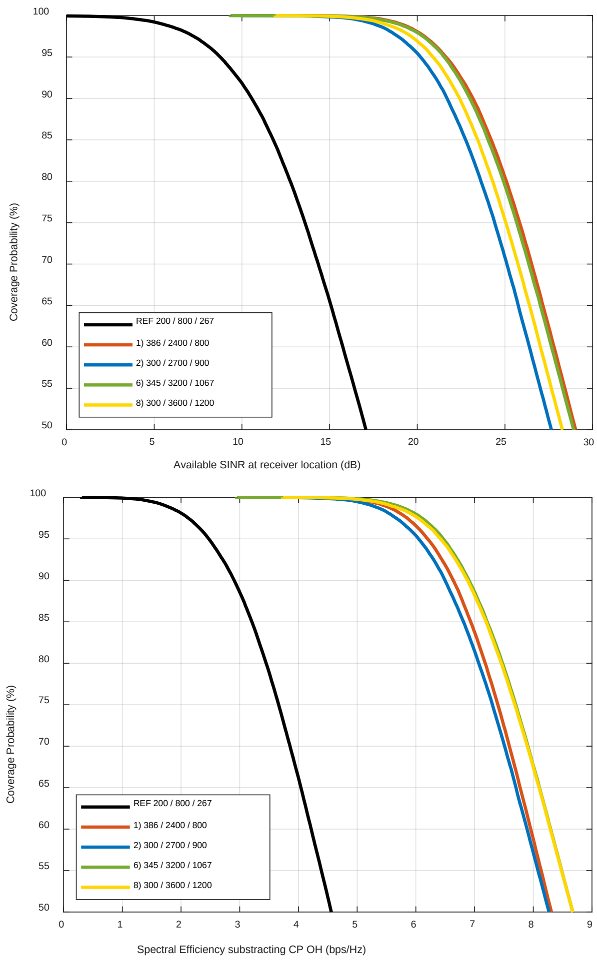


Figure 1: Achievable SINR and SEs for Coverage Probability, MPMT. Methodology a)

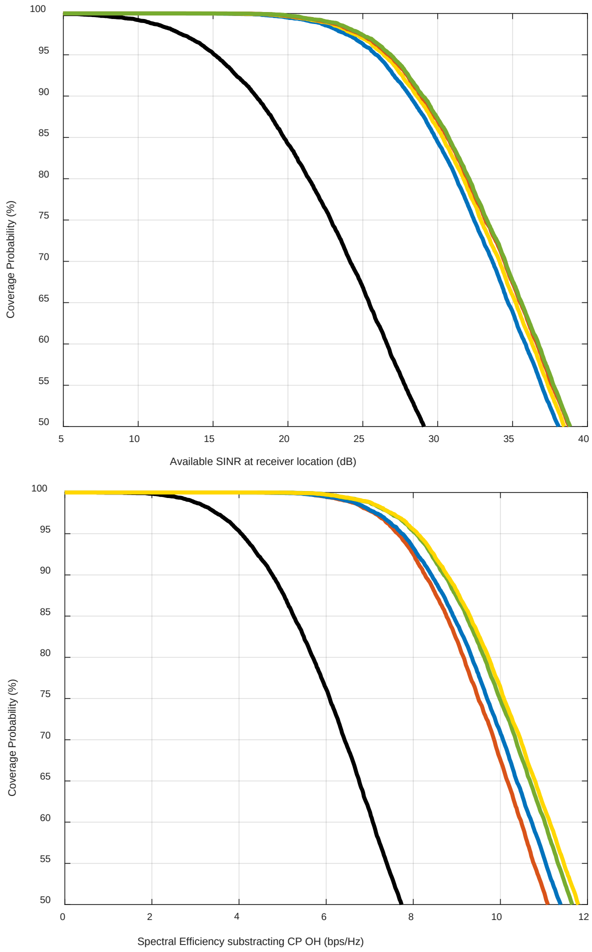


Figure 2: Achievable SINR and SEs for Coverage Probability, MPMT. Methodology b)

ID	Numerology	Methodology a)		Methodology b)	
		Achievable SINR (dB)	Spectral Efficiency (b/s/Hz)	Achievable SINR (dB)	Spectral Efficiency (b/s/Hz)
REF	200/800/267	8.8	2.5	10.5	2.9
1	386/2400/800	21.6	6.2	22.5	6.4
2	300/2700/900	20.2	6.0	21.6	6.5
6	345/3200/1067	21.5	6.5	22.6	6.8
8	300/3600/1200	20.9	6.4	22.2	6.7

Table 2: Achievable SINR and SEs for the Relevant Percentile of Coverage Probability, MPMT.

3.2 HPHT1

The complementary CDFs of the SINR and SEs for HPHT fixed rooftop are shown below in figure 3 for methodology a) and in figure 4 for methodology b). The corresponding SEs for both methodologies are set out at the relevant percentiles in table 3.

From table 3 it can be seen that the SEs are broadly similar for all the numerologies across both methodologies a) and b). However, methodologies a) and b) both show that numerologies 6 and 8 have marginally higher SE than numerology 2 which, noticeably, has the lowest SE.

Observation 2: Numerologies 1, 6 and 8 may be the best candidates for fixed rooftop reception in HPHT1.

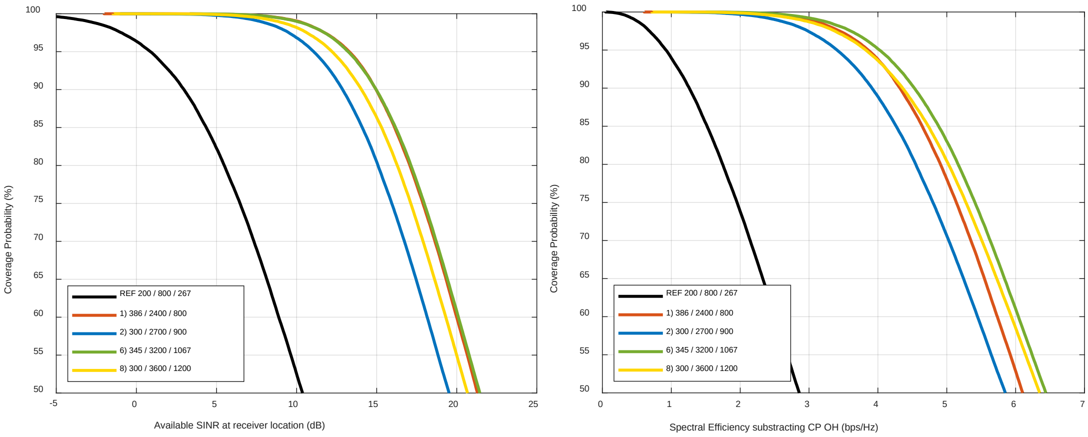


Figure 3: Achievable SINR and SEs for Coverage Probability, HPHT1. Methodology a)

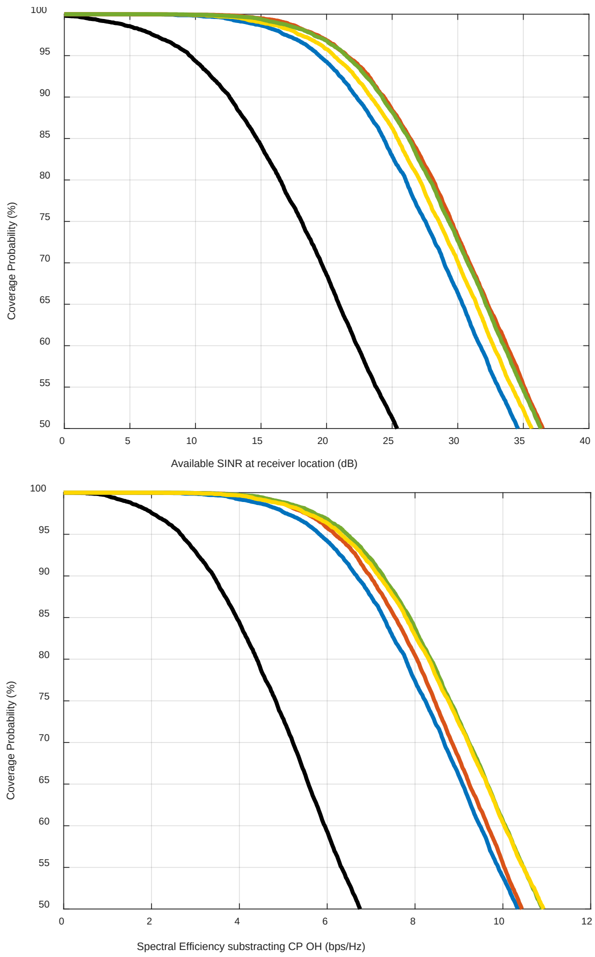


Figure 4: Achievable SINR and SEs for Coverage Probability, HPHT1. Methodology b)

ID	Numerology	Methodology a)		Methodology b)	
		Achievable SINR (dB)	Spectral Efficiency (b/s/Hz)	Achievable SINR (dB)	Spectral Efficiency (b/s/Hz)
REF	200/800/267	1	0.9	3.6	1.4
1	386/2400/800	13.3	3.9	16.8	4.8
2	300/2700/900	11.1	3.4	14.0	4.2

6	345/3200/1067	13.2	4.0	16.1	4.9
8	300/3600/1200	12.2	3.8	15.0	4.6

Table 3: Achievable SINR and SEs for the Relevant Percentile of Coverage Probability, HPHT1.

4. Summary

Based on the SEs derived from system level simulations the following observations may be made.

Observation 1: Numerologies 6 and 8 may be the best candidates for fixed rooftop reception in MPMT.

Observation 2: Numerologies 1, 6 and 8 may be the best candidates for fixed rooftop reception in HPHT1.

Observation 3: For both MPMT and HPHT1, numerology 6 provides the highest spectral efficiency with a smaller FFT compared with 8.

References

[1]. R1-1904007; “Discussion on new numerologies for PMCH to support rooftop reception”; Huawei, HiSilicon; 3GPP RAN WG1 #96; Xi’An, China, April 2019

[2]. R1-1905569; Chairman's notes of AI 6.2.4 LTE-based 5G Terrestrial Broadcast; 3GPP RAN WG1 #96; Xi’An, China, April 2019

[3]. R1-1811588, Scenarios and simulation assumptions for the LTE based terrestrial broadcast gap analysis, EBU, BBC, IRT; 3GPP RAN WG1 #94-Bis, Chengdu, China, October 2018

[4]. 3GPP TR 36.776; “Study on LTE-based 5G terrestrial broadcast (Release 16)”; 3GPP; March 2019

Acknowledgements

This work was supported in part by the European Commission under the 5G-PPP project Broadcast and Multicast Communication Enablers for the Fifth-Generation of Wireless Systems 5G-XCast (H2020-ICT-2016-2 call, grant number 761498). The views expressed in this contribution are those of the authors and do not necessarily represent the project.

References

[1] 3GPP TR 38.913 v14.3.0, “Study on scenarios and requirements for next generation access technologies,” June 2017.

[2] D. Vargas and D. Mi, Eds., “LTE-Advanced Pro Broadcast Radio Access Network Benchmark,” Deliverable D3.1, 5G-PPP 5G-Xcast project, Nov. 2017.

[3] T. Tran, Ed., “Mobile Core Network,” Deliverable D4.1, 5G-PPP 5G-Xcast project, May 2018.

[4] 3GPP TR 36.776 V1.1.0, “Study on LTE-based 5G Terrestrial Broadcast (Release 16)”, March 2019.

[5] B. Altman, Ed., “Session Control and Management,” Deliverable D4.3, 5G-PPP 5G-Xcast project, Nov. 2018.

[6] E. Garro, M. Fuentes, J.J. Gimenez and J.L. Carcel, Eds., “Air Interface,” Deliverable D3.2, 5G-PPP 5G-Xcast project, Nov. 2018.

[7] ETSI EN 300 401 V1.4.1" "Radio Broadcasting Systems; Digital Audio Broadcasting (DAB) to mobile portable and fixed receivers", June 2006.

[8] M. Saily and C. Barjau, Eds., “RAN Logical Architecture and Interfaces for 5G-Xcast,” Deliverable D3.3, 5G-PPP 5G-Xcast project, Feb. 2019.

[9] G. K. Walker, X. Zhang and X. F. Wang, "Extended duration cyclic prefix with low overhead for LTE Broadcast” U.S. Patent 2015/0078292 A1, issued March 19, 2015.

[10] 3GPP R1-1712879: “Forward Compatibility Consideration for ECP Design and NR-MBMS”, August 2017.

[11] J. J. Gimenez *et al*., "5G New Radio for Terrestrial Broadcast: A Forward-Looking Approach for NR-MBMS," in *IEEE Transactions on Broadcasting*. doi: 10.1109/TBC.2019.2912117