International Telecommunication Union

ITU-R

Radiocommunication Sector of ITU

Recommendation ITU-R M.2101-0

(02/2017)

Modelling and simulation of IMT networks and systems for use in sharing and compatibility studies

M Series

Mobile, radiodetermination, amateur and related satellite services

International Telecommunication Union

Foreword

The role of the Radiocommunication Sector is to ensure the rational, equitable, efficient and economical use of the radio-frequency spectrum by all radiocommunication services, including satellite services, and carry out studies without limit of frequency range on the basis of which Recommendations are adopted.

The regulatory and policy functions of the Radiocommunication Sector are performed by World and Regional Radiocommunication Conferences and Radiocommunication Assemblies supported by Study Groups.

Policy on Intellectual Property Right (IPR)

ITU-R policy on IPR is described in the Common Patent Policy for ITU-T/ITU-R/ISO/IEC referenced in Annex 1 of Resolution ITU-R 1. Forms to be used for the submission of patent statements and licensing declarations by patent holders are available from http://www.itu.int/ITU-R/go/patents/en where the Guidelines for Implementation of the Common Patent Policy for ITU-T/ITU-R/ISO/IEC and the ITU-R patent information database can also be found.

Series of ITU-R Recommendations

(Also available online at http://www.itu.int/publ/R-REC/en)

Series	Title
BO	Satellite delivery
BR	Recording for production, archival and play-out; film for television
BS	Broadcasting service (sound)
BT	Broadcasting service (television)
F	Fixed service
M	**Mobile, radiodetermination, amateur and related satellite services**
P	Radiowave propagation
RA	Radio astronomy
RS	Remote sensing systems
S	Fixed-satellite service
SA	Space applications and meteorology
SF	Frequency sharing and coordination between fixed-satellite and fixed service systems
SM	Spectrum management
SNG	Satellite news gathering
TF	Time signals and frequency standards emissions
V	Vocabulary and related subjects

Note*: This ITU-R Recommendation was approved in English under the procedure detailed in Resolution ITU-R 1.*

Electronic Publication
Geneva, 2017

RECOMMENDATION ITU-R M.2101-0

Modelling and simulation of IMT networks and systems for use in sharing and compatibility studies

(2017)

Scope

This Recommendation contains the methodology for modelling and simulation of IMT[1] networks for use in sharing and compatibility studies between IMT and other systems and/or applications. As such, it does not make any assumptions on the system parameters or modelling of these other systems and/or applications and is strictly limited to providing information for the IMT systems.

Keywords

IMT, IMT-Advanced, mobile systems, sharing/compatibility issues

Related Recommendations and Reports

Recommendation ITU-R M.2012 – Detailed specifications of the terrestrial radio interfaces of International Mobile Telecommunications Advanced (IMT-Advanced)

Report ITU-R M.2292 – Characteristics of terrestrial IMT-Advanced systems for frequency sharing/interference analyses

The ITU Radiocommunication Assembly,

considering

a) that Question ITU-R 229/5 addresses further development of the terrestrial component of IMT and the relevant studies under this Question are in progress within ITU-R;

b) that Resolution **223 (Rev. WRC-15)** invites ITU-R to conduct a number of compatibility studies between IMT systems and other systems and/or applications;

c) that Resolution **238 (WRC-15)** resolves to invite ITU-R to conduct appropriate sharing and compatibility studies between IMT systems and other systems and/or applications in a number of frequency bands;

d) that development of new radio interfaces that support the new capabilities of IMT-2020 is expected along with the enhancement of IMT-2000 and IMT-Advanced systems, consistent with Resolution ITU-R 57-2;

e) that methodologies for the modelling and simulation of IMT networks are needed to analyse compatibility between IMT systems and systems in other services;

f) that an accurate description of simulation of the transmissions of IMT networks, including the calculation of the aggregate effect, is required to realistically model IMT systems in sharing and compatibility scenarios,

[1] References to IMT in this Recommendation addresses modelling of IMT-Advanced and IMT-2020 networks.

recognizing

a) that Report ITU-R M.2292 provides the characteristics of terrestrial IMT-Advanced systems for frequency sharing/interference analyses;

b) that Recommendation ITU-R M.2012 contains the detailed specifications of the terrestrial radio interfaces of International Mobile Telecommunications Advanced (IMT-Advanced);

c) that Recommendations ITU-R M.2070 and ITU-R M.2071 provide the generic unwanted emission characteristics of base stations and mobile stations respectively, using the terrestrial radio interfaces of IMT-Advanced,

recommends

that the modelling and simulation of IMT networks and systems for use in sharing and compatibility studies should be based on the methodology contained in Annex 1;

List of abbreviations:

ACIR	adjacent channel interference power ratio
ACLR	adjacent channel leakage power ratio
ACS	adjacent channel selectivity
AAS	advanced antenna system
BS	base station
D2D	device-to-device
eMBB	enhanced mobile broadband
FD	full-dimension
FDR	frequency dependent rejection
HO	handover
M2M	machine-to-machine
MTC	machine-type communications
mMTC	massive machine-type communications
MIMO	Multiple Input Multiple Output
MBB	mobile broadband
OOB	Out-of-band
OOBE	out-of-band emission
RB	resource block
RF	radio frequency
UE	user equipment
URLLC	ultra-reliable and low latency communications

Annex 1

Methodology for modelling and simulation of IMT networks for use in sharing and compatibility studies

1 Introduction

This Annex contains the methodology for modelling and simulation of IMT networks for use in sharing and compatibility studies. It describes the appropriate IMT models to be used for sharing and compatibility studies between IMT and other radio systems in various frequency bands.

Definitions and basic concepts of IMT networks are described in § 2 to facilitate selection of the appropriate IMT model. Section 2 also provides information on technical elements such as output power and antenna pattern, antenna height and environment associated with deployment scenarios, density and distribution of IMT stations and information on propagation models for paths between IMT base stations and mobile stations.

It contains detailed IMT system parameters to be considered in such modelling and their implementation in the simulations as described in §§ 3 through 6. Specifically, § 3 contains simulation steps for modelling total emissions generated by an IMT network (in the case IMT is the interfering system) as well as modelling the impact on the IMT network (in the case IMT is the interfered-with system). Subsequently, considerations in calculating the aggregate effect of potential interference generated by an IMT system is described in § 7.

Furthermore, in order to emphasize the importance of realistically modelling IMT systems in sharing and compatibility scenarios, § 8 describes means to compare the implementation of modelling of IMT system through comparing interim results related to performance and operation of the IMT system.

2 Definitions and basic concepts

2.1 Usage scenarios

IMT-Advanced is the most widely accepted radio air-interface for the provision of mobile broadband (MBB). The IMT-2020 radio interface, in addition to supporting the enhanced mobile broadband (eMBB) use case, will support emerging use cases with a variety of applications such as massive machine-type communications (mMTC) and ultra-reliable and low latency communications (URLLC). The methodology is applicable for all the above scenarios and focuses mostly on MBB and eMBB scenarios, which are the dominant usage scenarios in sharing and compatibility studies.

Mobile broadband and enhanced mobile broadband are the result of applying more spectrally efficient technologies into larger amounts of spectrum, enabling higher data rate services. Massive machine-type communication is about connectivity for large numbers of low-cost and low-energy consumption devices in the context of the Internet of Things (IoT). Ultra-reliable and low latency communications are envisioned to enable real-time control and automation of dynamic processes in various fields, such as industrial process automation and manufacturing, energy distribution, intelligent transport systems – and requires communication with very high reliability and availability, as well as very low end-to-end latency.

Device-to-device (D2D) and machine-to-machine (M2M) communications may be used for mMTC and URLLC applications. In D2D/M2M communications, mobile stations initiate communications with base stations using their control channel. User data traffic is delivered by data channel directly among mobile stations. In this scenario, mobile stations are located within a cell area provided by a base station.

2.2 Deployment scenarios

From a deployment perspective, it is worthwhile categorizing IMT-Advanced and IMT-2020 radio access networks as either outdoor or indoor and as seamless wide area coverage or small area coverage.

Table 1 provides a high level description of IMT deployments. Categories 1 and 2 are the same as the existing configuration of IMT networks with seamless macro coverage. Categories 3 and 4 for coverage of small areas could be operated independently or combined with categories 1 and 2.

TABLE 1

Categories of radio access networks

MS Location	Seamless wide area coverage	Small area coverage
Outdoor MS	Category 1 Conventional Macro Cell (Omni, Sector Antenna, Beam forming Antenna)	Category 3 Outdoor Small Area Coverage (Omni, Sector Antenna, Beam forming antenna)
Indoor MS	Category 2 Coverage by Outdoor Macro Cell (Omni, Sector Antenna, Beam forming Antenna)	Category 4 Indoor Small Area Coverage (Omni, Sector Antenna, Beam forming antenna)

Furthermore, radio access networks may be classified to each deployment scenario by considering the following aspects:

a) environments (Rural / Suburban / Urban / Indoor);

b) seamless wide area coverage / Small area coverage.

Six deployment scenarios are defined in Table 2 as combinations of the above aspects a) and b). Three deployment scenarios of macro rural, macro suburban and macro urban are the same as the existing configuration of IMT networks with seamless macro coverage. The other three deployment scenarios of micro suburban, micro urban and indoor are deployed to cover small areas.

The latter three deployment scenarios could be operated independently in some cases, whereas it could be often the case that they are operated combined with the former three deployment scenarios.

The classification of deployment scenarios in Table 2 is applicable to relevant IMT models and associated propagation environments to apply appropriate IMT modelling for sharing studies.

TABLE 2

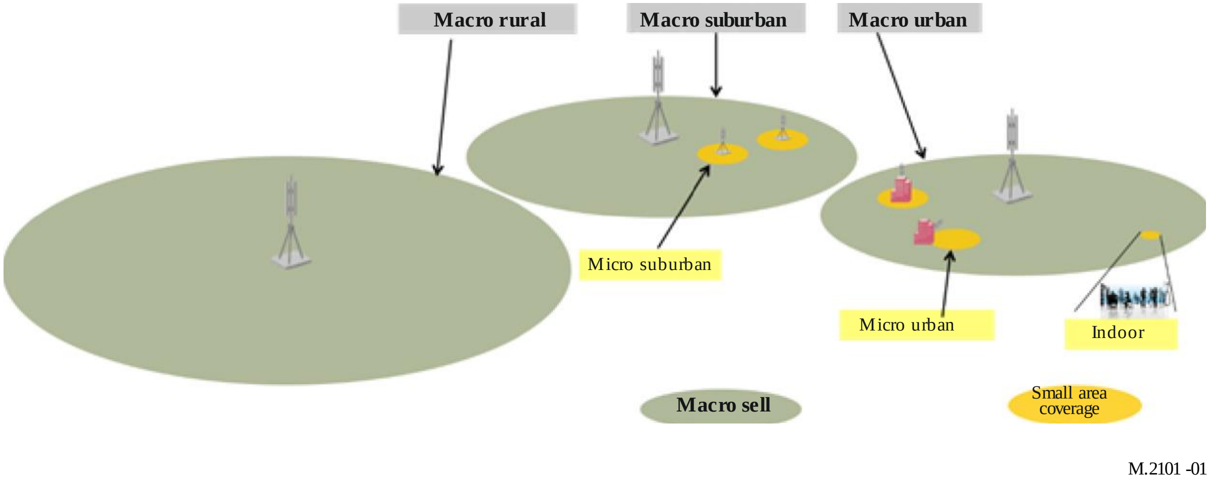
Deployment scenarios of radio access networks

Base station location	Seamless wide area coverage	Small area coverage
Rural	Macro rural	Not applicable
Suburban	Macro suburban	Micro suburban
Urban	Macro urban	Micro urban
Indoor	Not applicable	Indoor

An illustration of possible scenarios is provided in Fig. 1 and further described below.

FIGURE 1

Example deployment scenarios



(1) Macro rural

The rural deployment scenario focuses on larger and continuous wide area coverage. Base station antennas are typically deployed at the top of tower.

(2) Macro suburban

The macro suburban scenario focuses on seamless coverage of suburban areas (mainly residential) as well as rural towns with low-rise buildings, but not including the unpopulated areas between them. Base station antennas are typically deployed on tower/rooftop and users can be either outdoors and indoors.

(3) Macro urban

The macro urban scenario focuses on multi-story buildings with base station antennas typically at or above the level of the roofline. Base station power may vary depending on local deployment and coverage needs. Users can either be outdoors or indoors. Repeaters for indoor coverage, if any, are considered equivalent to, and therefore treated as, user equipment (UEs).

(4) Micro suburban

The micro suburban scenario focuses on capacity enhancement in small community areas with low-rise buildings in suburban areas. Base station antennas are typically deployed mounted on poles. Users can either be outdoors or indoors. Repeaters for indoor coverage, if any, are considered equivalent to, and therefore treated as, UEs.

(5) Micro urban

The micro urban scenario focuses on multi-story buildings with base station antennas below the roofline. Base station antennas are typically deployed as single sector antennas or beam forming antennas with low output power. The deployment scenario has an environment that blocking and/or multiple diffractions/scattering are dominant near the antennas, such as street micro cell and small hot spot, from the viewpoint of propagation effects. Users can either be outdoors and indoors.

(6) Indoor

The indoor scenario occurs most often in urban or suburban environments. Base stations and users are indoors.

2.3 Transmit power control

Studies to assess the impact of an entire IMT network should take into account the varying nature of an IMT network, in particular power control.

For uplink, some device types (e.g. low power devices for MTC applications) may operate without any power control while for other types (e.g. enhanced mobile broadband devices) power control will be used. Power control compensates fully or partly for the difference in coupling loss between the different devices connected to the BS and has an initial receive target level per resource block (RB).

For downlink, a number of base station types (Macro, Micro, Pico, Femto, etc.) are used, each having a different EIRP level. Output power of base stations for micro urban and indoor in § 2.2 is generally less than that for other deployment scenarios. No downlink power control scheme is applied at the base station and the transmission power per resource block (RB) is constant. The total downlink power is varied according to the number of RBs used. However, in this Recommendation this effect is modeled in a different way. (See § 3.4).

2.4 Advanced antenna technology and characteristics

Over the past years IMT base station antennas have been developed to optimize the transmission or reception of signals. Also, in IMT terminals the number of receive antennas has increased.

With multiple antenna elements at both the base station and the terminal, new capabilities are possible. Multiple Input Multiple Output (MIMO) allows multiple signal streams to be used for transmit diversity, spatial multiplexing, beam shaping or null steering in one direction or another.

IMT-2020 will, in addition to operation in lower frequency ranges, also operate in higher frequency bands. Antenna size scales with frequency allowing base stations and terminals to exploit smaller antenna footprint with increased number of antenna elements at higher frequencies. Increased number of antenna elements support narrower beam shapes and can reduce the potential interference into other than the intended receiver. Also, higher beam gain can mitigate the higher path loss at higher, e.g. mm-wave, frequencies and support multiple signal streams to multiple users (a.k.a. multi user (MU)-MIMO).

2.5 Antenna height and environment structures

There are few high architectural structures to obstruct line-of-site propagation around base station antennas in rural environment. Whereas, higher and denser architectural structures appear around base station antennas as the environment varies from suburban to urban. Therefore, the propagation would be affected based on the position of base station antennas and architectural structures around them.

2.6 Density and distribution of stations

It is necessary to consider flexible density and distribution of radio stations in aggregate interference calculations. Demands for high data rate traffic mainly occurs in discrete hot-spot regions. Deployments in higher frequency bands often do not cover all areas in a country/region, as coverage might be complemented using lower frequency bands.

2.7 Propagation models

IMT exists in many deployment configurations, from a single layer homogenous network, e.g. a macro network, to multiple layer heterogeneous networks, e.g. macro/micro network or macro/pico network or micro/pico network etc., and has to handle outdoor to outdoor, outdoor to indoor and indoor propagation environments for several frequency ranges.

In addition, propagation environment between the IMT system and systems of other services subject to any coexistence conditions need to also be taken into account. Several models already exist as P-series ITU-R Recommendations or ITU-R Reports. For calculation of the path loss between the IMT base stations and UEs, see also Report ITU-R M.2135.

Propagation effects between the interfering and the interfered-with systems are outside the scope of this document. However, when choosing propagation models the deployment environments of the IMT systems, including the position of the base station antennas, surrounding physical structures and operating frequencies, should be taken into account.

2.8 Repeaters for indoor coverage

In order to overcome large indoor penetration loss, it might be practical to utilize wall-mounted repeaters on the outside of buildings or placed by the window inside buildings to easily obtain near line-of-sight propagation toward a base station.

2.9 Protection criteria for IMT

Protection criteria are given in ITU-R documents such as Report ITU-R M.2292, which provides I/N as the protection criterion. The I/N is the ratio of the allowed inter-system interference level received in the IMT receiver relative to the receiver’s noise level (thermal noise + receiver noise figure).

In modelling IMT networks, the degradation of carrier to interference plus noise (C/(I+N)) could also be used to evaluate throughput loss or outage of the IMT system caused by inter-system interference.

3 Simulation set up

For modelling and simulation of IMT networks for use in co-existence studies, it is essential to select appropriate deployment conditions. The assumed deployment conditions are critical aspects that will directly impact the results of any sharing study. Examples of such factors are realistic choice of the environment in which the assumed IMT network operates (urban/suburban/rural) and the frequency bands that are to be used in the IMT simulation. In addition, density and distribution of stations and EIRP may be considered depending on factors such as the size of the area over which interference is aggregated. Other factors that need consideration are discussed briefly below.

3.1 Network topology

There are two different types of network structure: Homogeneous networks and Heterogeneous networks. A homogeneous network structure consists of a single base station type. It can be a macro, a micro or an indoor base station. A heterogeneous network structure consists of combination of at least two base station types. For a large area or nationwide studies a combination of network structures may be required.

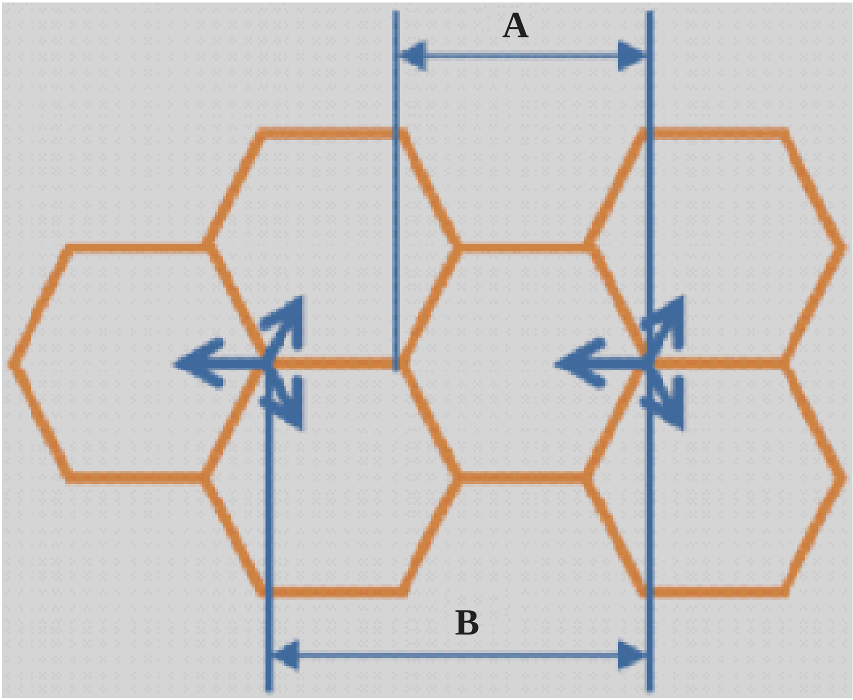
3.1.1 Macro cellular network

Macro base stations are often deployed above roof-top. Figure 2 illustrates the geometry for a 3-sector deployment, and illustrates the parameters cell radius (A) and inter-site distance (B). Each cell (also referred to as a sector) is shown as a hexagon, and in this Figure there are three cells/sectors per base station site. Cell sizes in IMT networks can vary considerably depending on the environment, carrier frequency and the base station's type.

In large area or nationwide sharing studies using cell radii corresponding to urban and suburban deployment should take into account those that are only deployed in limited, central areas of large cities and suburban areas.

FIGURE 2

Macro cell geometry

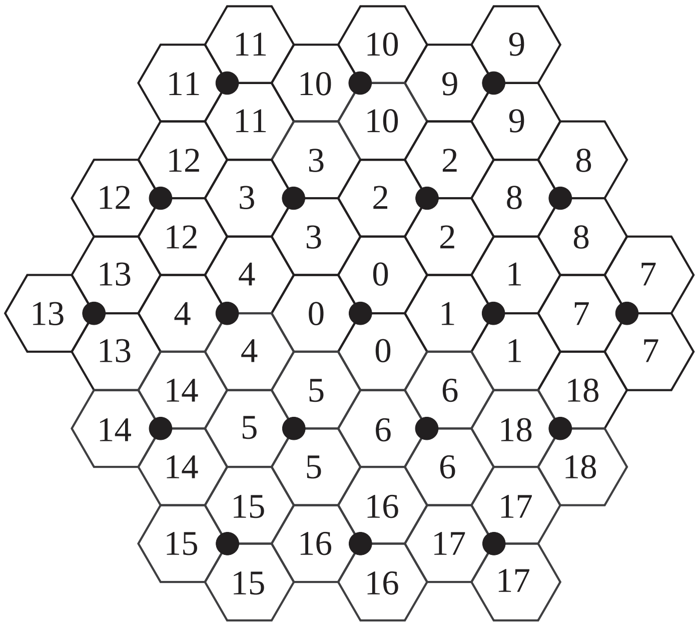


M.2101-02

One example of a macro network topology is depicted in Fig. 3. The entire network region relevant for simulations is a cluster of nineteen sites of three sectors each (sites 0 to 18 in the Figure), where other clusters of 19 sites are repeated around this central cluster based on a wrap-around methodology employed to avoid the network deployment edge effects. (See Attachment 2 for information on wrap-around methodology.) In some scenarios, for example in cross-border situations, modelling of the edge effects may be required.

FIGURE 3

Macro cellular layout (central cluster)



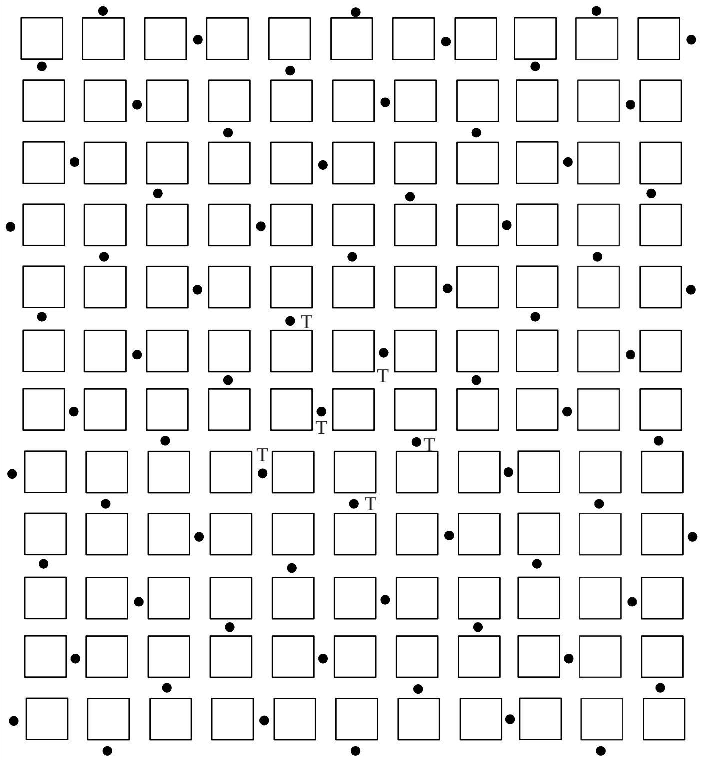
M.2101-03

3.1.2 Micro-cellular network

In the urban environment, micro base stations are generally deployed below roof-top. One example of a Micro cell topology [2] is the so-called Manhattan model. Micro cell base stations are placed in the Manhattan grid as proposed in Fig. 4.

FIGURE 4

Micro cell topology



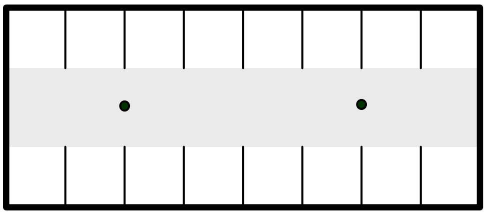
M.2101-04

3.1.3 Indoor hotspot

In this scenario, the base stations are deployed indoors. An example indoor hotspot scenario consists of one floor of a building. The topology of an indoor cell is shown in Fig. 5. The indoor cell sizes will vary depending on the frequency band and the configuration of the building interior. Similar deployments would be used to simulate each floor in a multi-floor sharing scenario. If an indoor IMT system is considered as an interfering system, indoor penetration loss should be taken into account.

FIGURE 5

Indoor hotspot layout



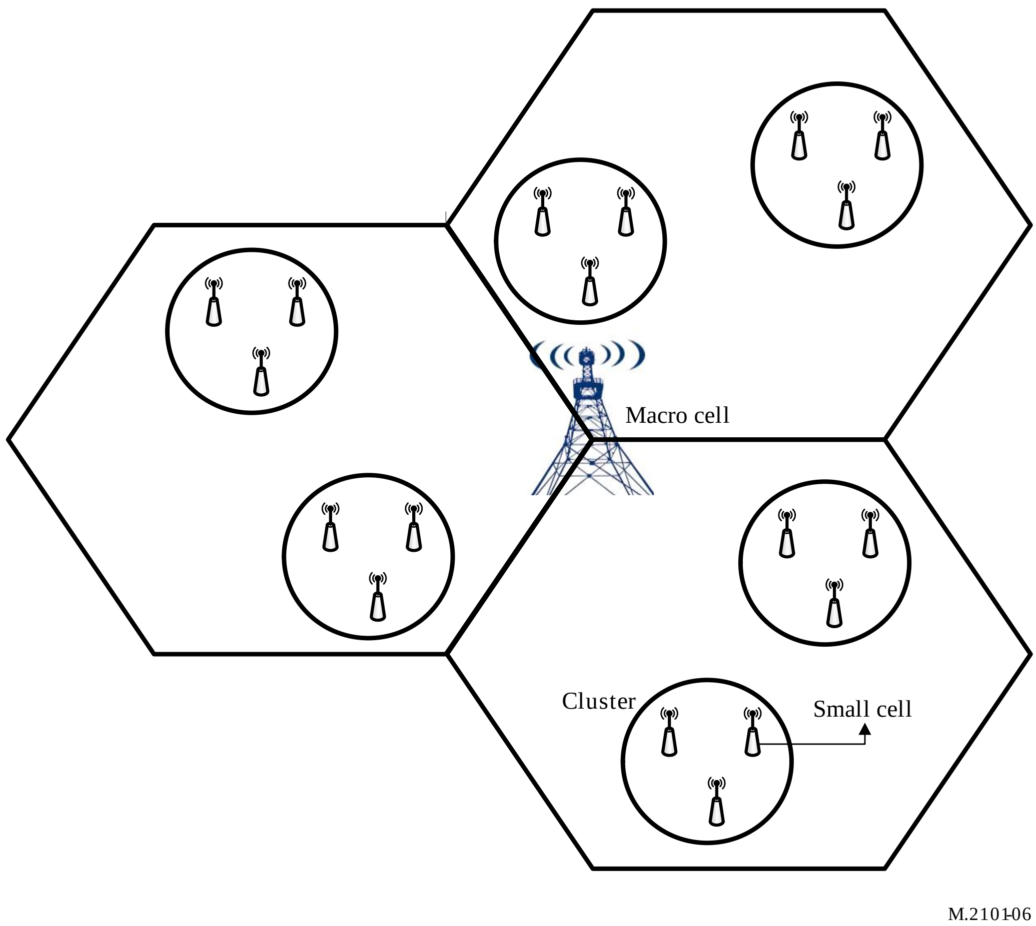
M.2101-05

3.1.4 Heterogeneous network

An example of a heterogeneous network is depicted in Fig. 6 and is composed of macro cells and microcells. Several micro cell clusters are distributed in a macro cell coverage area. Each cluster consists of a number of cells which can either be positioned randomly or be positioned in fixed and predetermined positions.

FIGURE 6

Heterogeneous network layout



Based on the layout described in Fig. 6, the creation of the random process used in the distribution of micro base station may be made in two successive steps:

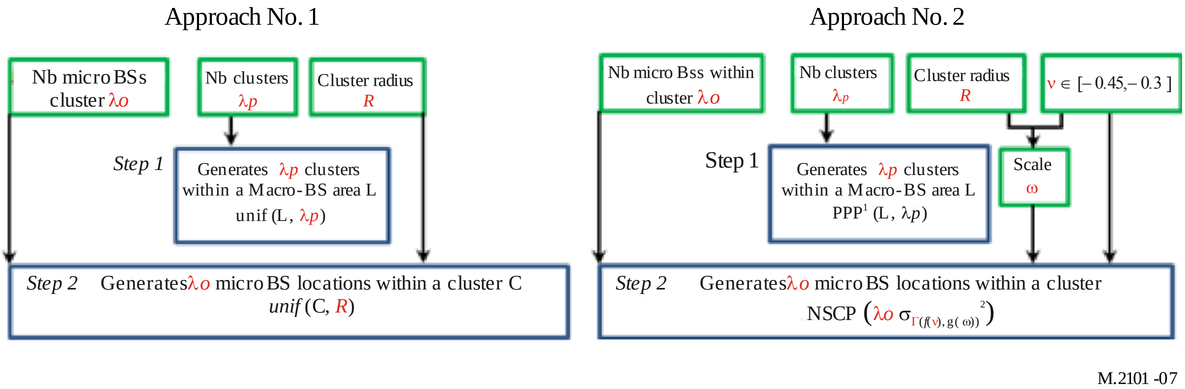
step 1: generating λ_p clusters within the macro cell area following a distribution $D_{cluster}$,

step 2: generating within each cluster λ_o micro BSs locations following a distribution D_{BS}

Two different approaches following these steps are described. They both involve the topology of the micro BS with the number of clusters λ_p and the cluster radius R on which the number of micro BSs λ_o within each cluster are located.

FIGURE 7

Flowchart to generate micro BSs



In Fig. 7 above, Approach 1 is based on [1] and assumes a uniform random distribution (within a macro geographical area) for the clusters as well as the micro BSs locations within each cluster while the Approach 2 based on real deployments of micro-BSs [8] requires an additional parameter v and considers different probability distributions for the cluster (Poisson Point Process (PPP)) and the micro BS locations (Variance Gamma σ_Γ). See Attachment 1 for more information about the meaning and the relationship between R, ω and v. It should be noted that although application of both approaches is valid in sharing studies, approach 2 might be more suitable for the case where the interfered-with receiver of the non-IMT service is located close to the IMT base stations (e.g. within the same urban environment).

In order to avoid strong interference from the macro cell, the micro cell usually uses another frequency band. For a network using different frequencies for the two IMT layers, it is sufficient in a sharing study to only simulate the layer adjacent to or overlapping with the interfered-with system frequency. However, such a simulation should consider that not all traffic is carried in the simulated IMT layer.

For a network using multiple frequency bands, the macro cell would use the lower frequency band for full coverage.

3.2 Modelling of IMT networks for interference calculation

Different types of interference should be taken into account in sharing and compatibility studies depending on different scenarios. These are described in this section.

For scenarios involving IMT and non-IMT systems the co-channel and adjacent channel effects could be considered jointly as frequency dependent rejection (FDR) as described in Recommendation ITU-R SM.337.

3.2.1 Co-channel emissions

In a scenario where the interferer and interfered-with systems operate on the same frequency (co-channel), the dominant type of interference to be taken into account is that resulting from the co-channel transmitted power of the interferer.

3.2.2 Adjacent channel emissions

In an adjacent band scenario where the interferer and interfered-with system operate on different frequencies, two types of interference need to be accounted for:

− interferer unwanted emissions: Unwanted emissions consisting of out-of-band emissions and spurious emissions;

− interfered-with system receiver blocking performance: the receiver ability to receive a wanted signal within the bandwidth of its assigned channel in the presence of interference.

3.2.2.1 Interferer unwanted emissions

3.2.2.1.1 Out-of-band (OOB) emission interference

Interferer OOB emission represents the unwanted emission on a frequency or frequencies immediately outside the necessary bandwidth which results from the modulation process, but excluding spurious emissions.

For IMT systems, the interferer OOB emission interference P_{tx}^{OOB} could be calculated as follows:

$$P_{tx}^{OOB} = P_{tx} - ACLR \quad \text{dB} \tag{1}$$

where:

P_{tx} (dBm): Output power of interferer transmitter

ACLR (dB): Adjacent channel leakage power ratio, which is the ratio of the filtered mean power (integrated over assigned channel bandwidth) centred on the assigned channel frequency to the filtered mean power (integrated over adjacent channel bandwidth) centred on an adjacent channel frequency. ACLR can be also derived from out-of-band emission mask which is given in related specifications e.g. 3GPP[6][7].

Information on the OOB emissions from other (non-IMT) systems may also be required, which may or may not be defined by ACLR.

3.2.2.1.2 Spurious emission interference

Spurious emission represents the unwanted emission on a frequency or frequencies which are outside the OOB emission domain and the level of which may be reduced without affecting the corresponding transmission of information. Spurious emissions include harmonic emission, parasitic emission, intermodulation products and frequency conversion products, but exclude out-of-band emissions.

For IMT systems, the value of spurious emission $P_{tx}^{spurious}$ defined in a given frequency band can be found in the related specifications e.g. Report ITU-R M.2292, and in 3GPP.

Similar to the OOB emission, an equivalent ACLR value ($ACLR_{equiva}$) can be calculated for spurious emission and used in the simulation. Then the value of $P_{tx}^{spurious}$ could be derived as below,

$$P_{tx}^{spurious} = P_{tx} - ACLR_{equiva} \quad \text{dB} \tag{2}$$

Information on the spurious emissions from other (non-IMT) systems may also be required which may or may not be defined by ACLR.

3.2.2.2 Blocking interference

The blocking characteristic is a measure of the receiver ability to receive a wanted signal at its assigned channel in the presence of an unwanted interferer.

For IMT systems, the value of blocking interference $P_{blocking}$ could be derived as below,

$$P_{blocking} = P_{rx} - ACS \quad \text{dB} \tag{3}$$

where:

P_{rx} (dBm): Interfering signal mean power at the receiver

ACS (dB): Adjacent channel selectivity is a measure of a receiver's ability to receive a signal at its assigned channel frequency in the presence of a modulated signal in an adjacent channel. ACS value can be calculated from ACS/ blocking interference level defined in related specifications. See Report ITU-R M.2039-3, note (27) to Table 2, or 3GPP TR 36.942.

Information on the blocking characteristics of other (non-IMT) systems may also be required which may or may not be defined by adjacent channel selectivity (ACS).

3.2.3 ACIR/FDR

The adjacent channel interference power ratio (ACIR) is defined as the ratio of the total power transmitted from a source (base station or UE) to the total interference power affecting an interfered-with receiver, resulting from both transmitter and receiver imperfections. ACIR is commonly used in situations where both interferer and interfered-with systems are IMT systems. Therefore the ACIR is a combined value of the two interference types (unwanted emissions and blocking interference) which is calculated according to equation (4) with ACLR and ACS expressed in linear form.

$$ACIR^{-1} = ACLR_{TX}^{-1} + ACS_{RX}^{-1} \tag{4}$$

If ACS and ACLR values are not available, ACIR value could be replaced by FDR value as described in Recommendation ITU-R SM.337.

3.2.4 The characteristics of actual IMT equipment implementations

The achievable performance of actual IMT equipment implementations, such as unwanted emission levels or blocking performance, is usually better under normal condition than those specified in the standards.

Therefore, when modelling IMT systems, practical design consideration of IMT equipment could be taken into account. Where information is available, e.g. measurement results of unwanted emission levels of actual equipment implementations, the difference between specified and measured values may be taken into account when modelling IMT systems.

3.3 FDD/TDD networks

IMT networks may operate as either a Frequency-division duplexing (FDD) network (using different frequency band for uplink and downlink), as a Time division duplexing (TDD) network (using same frequency band for uplink and downlink under synchronized/un-synchronized, fixed or variable uplink/downlink ratio conditions) or as a downlink/uplink only network. IMT modelling has to take this into account when creating a simulation scenario.

If aggregated interference towards an interfered-with system arises from a large/very large earth area such as at a satellite or high altitude platform, the simulator may need to be able to take into account several geographically separated IMT networks.

3.4 Simulation Methodology

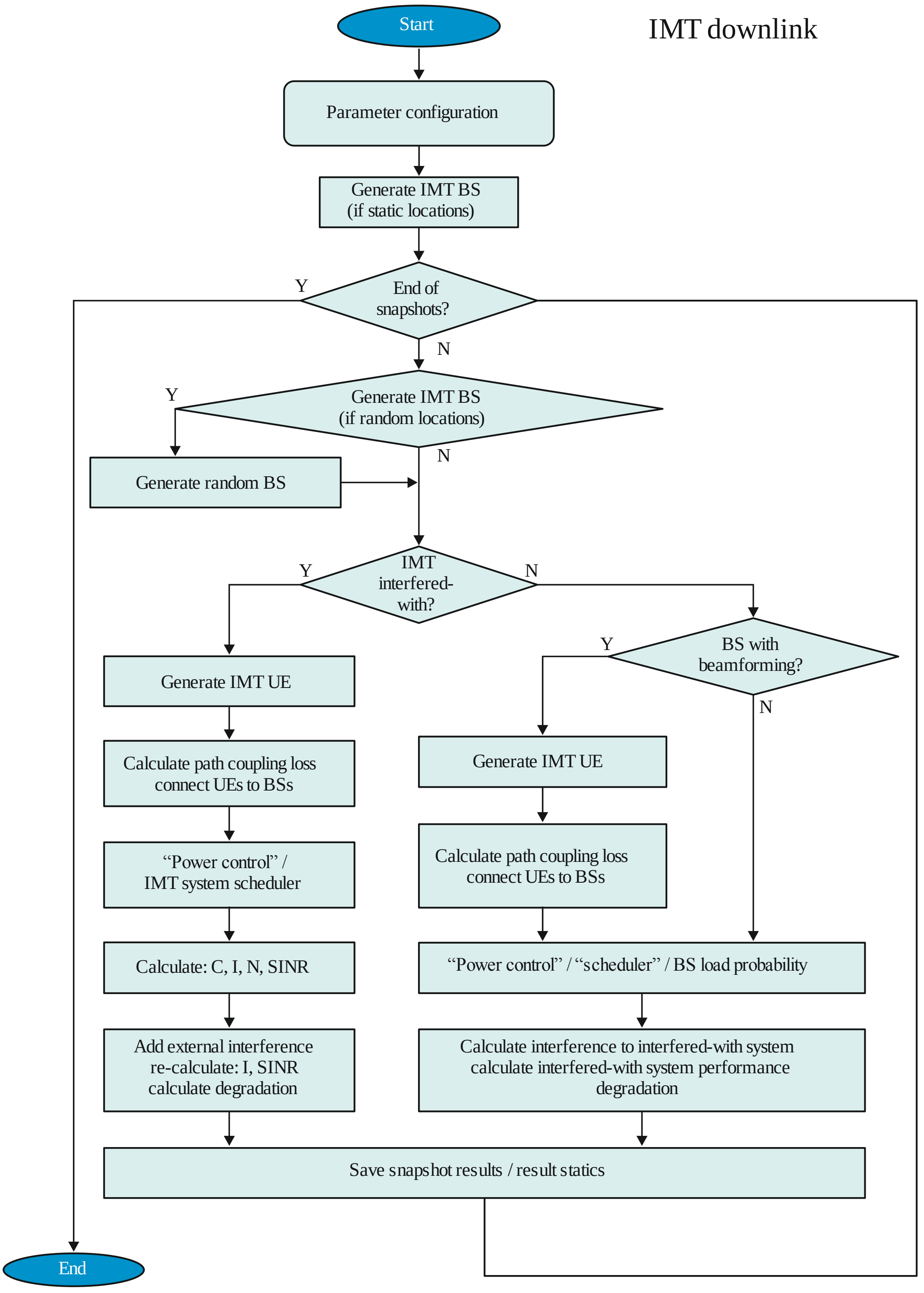
This section outlines the simulation methodology steps to be followed in order to generate uplink or downlink emissions from an IMT network for the purpose of coexistence studies.

The method is a system-level simulation which is widely used in sharing and compatibility studies involving IMT networks. This method is based on a Monte Carlo analysis, which enables assessing interference likelihood by simultaneously simulating the inter-system interference from multiple interfering sources. Influence caused by different topology assumptions, different power control algorithms and different interfering transmitter distribution densities are also reflected in the evaluation result. It should be noted that the method to calculate non-IMT interfered-with system performance degradation, shown in Figs. 8 and 9, as well as modelling of other systems are outside the scope of this document.

The static method described below could serve as a basis for more elaborate models which e.g. take time into account. Such a model would account for the variation of interference level with time for example in the case of moving UEs interfering with terrestrial systems without retransmission, e.g. broadcasting receivers. The typical flow-chart of the static simulation is stated as below.

FIGURE 8

Flowchart of simulation downlink method



M.2101 -08

3.4.1 Downlink

Create a base station (BS) grid (if static with fixed positions) depending on the selected use case/deployment scenario.

For i=1 to number of snapshots

1 Some of the steps a. to f. may not be needed per snapshot depending on the selected flow chart path.

a. Create/Distribute randomly BS nodes in case of BS grid with random positioned BS nodes.

b. Distribute sufficient[2] number of UEs randomly throughout the system area such that the same number *K* of "chosen" users (UEs that receive data from BSs in this snapshot)) is allocated to each cell within the handover (HO) margin. The value of *K* will depend on use case/deployment scenario, frequency and bandwidth. Calculate the path coupling loss (max {propagation loss+fading+antenna gains}, MCL) from each UE to all BSs. If the BS grid uses wrap-around, also identify the smallest coupling loss values between UEs and BSs.

c. Link the UE randomly to a BS to which the path coupling loss is within the smallest coupling loss plus the HO margin.

d. Select *K* UEs randomly from all the UEs linked to one BS as "chosen" UEs. These *K* "chosen" UEs will be scheduled during this snapshot. If beamforming is used, point selected BS/UE beams toward each other.

e. All available resource blocks (RBs) will be allocated to "chosen" UEs and each UE is scheduled with the same number *n* of RBs. Thus, the BS transmitted power per UE is fixed.

f. BSs are transmitting with full power or are silent with a load probability, i.e. *x*% of the BSs is randomly selected to transmit and the rest remain silent. See § 6.

The value of *x* can either be a single number or selected randomly from a range in each snapshot.

For those BSs that transmit, the power per UE[3] is calculated as follows:

Let P_{BS}^{Max} denote the maximum transmit power of BS

$M = n \times K$ is the number of all available RBs for each BS

P_{BS}^{UE} is the transmit power from BS to the "chosen" UE, and

n is the number of resource blocks per UE,

$$P_{BS}^{UE} = P_{BS}^{Max} \frac{n}{M} \tag{5}$$

Continue with Step 2 if IMT downlink acts as an interfering system.

Continue to Steps 3 if IMT downlink is an interfered-with system.

2. Select IMT DL to act as interferer.

a. Randomly select *x*% of the BSs depending on system load and interference conditions (closest interferer or aggregated interference) to act as interferer towards the interfered-with system.

---

[2] "The sufficient number of dropped (distributed) devices will both depend on used drop method, i.e. if the random drop is made within each BS coverage area or random within the entire network coverage area, and on the number *K* that should be allocated to each BS. Normally sufficient number varies between 2**K* and 10**K* in order to achieve requested allocation per BS depending on used drop method."

[3] As shown in the flow chart, one possible path does not require creation of UEs. For this path set $P_{BS}^{UE} = P_{BS}^{Max}$ for continued action in steps 2 and 6.

b. Assuming that the interfered-with system is modeled, apply interference towards the interfered-with system and calculate its performance degradation.

Calculate external interference from each downlink of IMT system to the interfered-with system.

Loop over all selected BSs from $j=1$ to N_{cell} (the number of selected BSs in the system area);

Loop over all "chosen" UEs in the selected BS from $k=1$ to K, then interference from BS_j (when K-th UE is served) can be calculated as below;

$$I_{External}(TX_{BS_j}^{UE_k}, RX^{victim}) = P_{BS}^{UE} \times CL_{External}(TX_{BS_j}^{UE_k}, RX^{victim}) \;/\; ACIR_{linear} \tag{6}$$

where:

$CL_{External}(TX_{BS_j}^{UE_k}, RX^{victim})$: Coupling loss from BS_j (when its k-th UE is served) of IMT system to the interfered-with receiver which includes path loss, penetration loss, shadow fading and antenna gain at transmitter/receiver.

Replace $ACIR_{linear}$ with FDR in case FDR is used.

$I_{External}(TX_{BS_j}^{UE_k}, RX^{victim})$: Inter-system interference from BS_j (when its k-th UE is served) to the interfered-with receiver.

The aggregate external-system interference is denoted by:

$$I_{External} = \sum_j \sum_k I_{External}(TX_{BS_j}^{UE_k}, RX^{victim}) \tag{7}$$

where:

$I_{External}$: aggregate external system interference towards the interfered-with system.

Calculate impact on the interfered-with system from external interference. Calculation of the impact on non-IMT interfered-with system is outside the scope of this Recommendation and depends on the sharing scenario.

c. Continue to step 6.

3. Select IMT DL as the interfered-with system.

a. Randomly select x% of the BSs depending on system load

b. Calculate DL C/I for all "chosen" UEs.

Loop over all selected BSs from $j=1$ to N_{cell} (the number of selected BSs in the system area)

Loop over all "chosen" UEs in selected BSs from $k=1$ to K.

For the k-th "chosen" UE in the j-th cell (i.e., $UE_{j,k}$) its C/I is denoted by $\frac{C(j,k)}{I(j,k)}$.

$C(j,k)$ is the received power from the serving BS, i.e. the j-th BS.

$$C(j,k) = P_{BS}^{UE} \times pathCouplingLoss(UE_{j,k}, BS_j) \tag{8}$$

$I(j,k)$ is the interference power which consists of intra systems interference (from other cells in own network) $I_{\mathrm{intra}}(j,k)$, and thermal noise N_t.

$$I(j,k) = I_{\mathrm{intra}}(j,k) + N_t \tag{9}$$

$$I_{\mathrm{intra}}(j,k) = \sum_{l=1, l \neq j}^{N_{cell}} P_{BS}^{UE} \times pathCouplingLoss(UE_{j,k}, BS_l) \tag{10}$$

$$N_t = 10\,\hat{}\,((10\log_{10}(kT) + 10\log_{10}(bandwith\ of\ n\,RBs) + NoiseFigure_{UE})/10) \tag{11}$$

where $10\log_{10}(kT)$ is the noise power spectral density in dBm.

4. Add external interference Zy, consisting of y interferers each with a power $P_{ext,y}$. If interference only occurs in one or few cells, main interference should be placed in an active cell (i.e. a cell with a selected BS).

   Calculate externally interfered DL C/I=($\frac{C(j,k)}{I(j,k)}$) for all “chosen” UEs.

   $C(j,k)$, $I_{\mathrm{intra}}(j,k)$ and N_t are the same as in step 3.

$$I(j,k) = I_{\mathrm{intra}}(j,k) + I_{external}(j,k) + N_t \tag{12}$$

$$I_{external}(j,k) = \sum_{m=1}^{y} P_{ext,m} \times pathCouplingLoss(Z_m, UE_{j,k}) / ACIR_{linear} \tag{13}$$

   The ACIR value should be calculated based on per UE allocated number of resource blocks. Replace $ACIR_{linear}$ with FDR in case FDR is used.

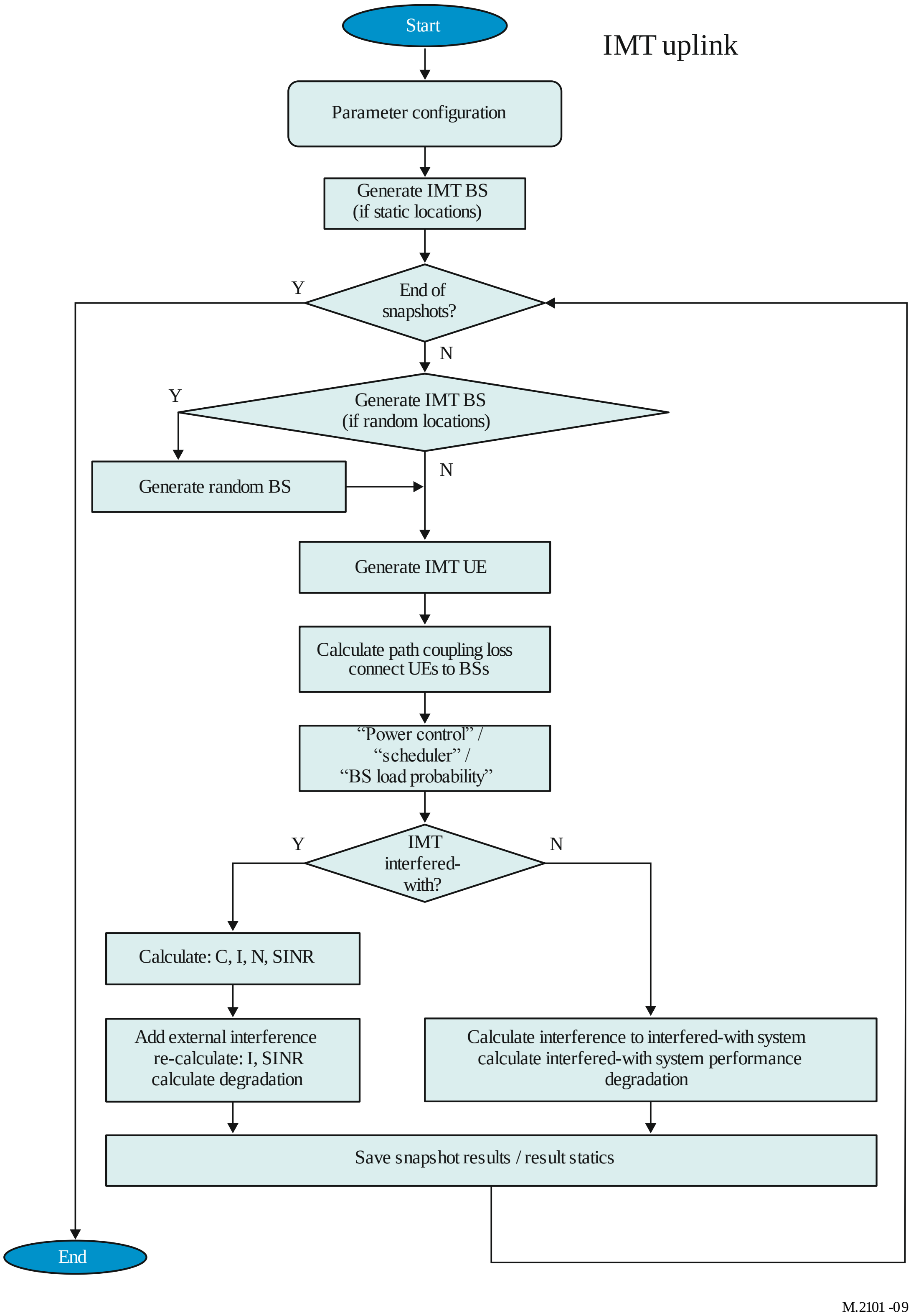
5. Determine the throughput with and without external interference for each “chosen” UE with the C/I according to the link-to-system level mapping.

6. Collect statistics.

3.4.2 Uplink

FIGURE 9

Flowchart of simulation uplink method



Create a BS grid (if static with fixed positions) depending on the selected use case/deployment scenario.

For i=1 to number of snapshots

1. Some of the steps a. to f. may not be needed per snapshot depending on the selected flow chart path.

   a. Create/Distribute randomly BS nodes in case BS grid with random positioned BS nodes.

   b. Distribute sufficient[4] number of UEs randomly throughout the system area such that the same number K of "chosen" users is allocated to each BS within the HO margin of 3 dB. The value of K will depend on the use case/deployment scenario, frequency and bandwidth. Typically K in the interval of 3 to 6 has been used in MBB studies.

   c. Calculate the path coupling loss (max{propagation loss+fading+antenna gains}, MCL) from each UE to all BSs. If the BS grid uses wrap-around, also identify the smallest coupling loss values between UEs and BSs.

   d. Link the UE randomly to a BS to which the path coupling loss is within the smallest coupling loss plus the HO margin.

   e. Select K UEs randomly from all the UEs linked to one BS as "chosen" UEs. These K "chosen" UEs will be scheduled during this snapshot.

   f. The power per UE is determined by UL power control.

   g. A fully loaded base station is assumed, namely, all available RBs are allocated to active UEs. Each UE is scheduled with the same number n of RBs. UEs connected to a BS may or may not be transmitting based on a load probability, i.e. UEs in x% of the randomly selected BSs are transmitting and the remaining UEs remain silent. See § 6. The value of x can either be a single number or selected randomly from a range in each snapshot.

2. Perform UL power control

   Continue to Step 3 if IMT uplink acts as an interfering system. Continue to Step 4 if IMT uplink is the interfered-with system.

3. Select IMT UL to act as interferers

   a. Randomly select x% of the BSs depending on system load and interference conditions (closest interferer or aggregated interference). Select UEs connected to those BSs to act as interferers towards the interfered-with system.

---

[4] "The sufficient number of dropped devices will both depend on used drop method, i.e. if the random drop is made within each BS coverage area or random within whole network coverage area, and on the number K that should be allocated to each BS. Normally sufficient number varies between 2*K and 10*K in order to achieve requested allocation per BS depending on used drop method."

b. Apply interference towards the interfered-with system and calculate its impact:

Loop over all selected BSs from $j = 1$ to N_{cell} (the number of selected BSs in the system area);

Loop over all "chosen" UEs in selected BSs from $k = 1$ to *K*.

Calculate external interference from each IMT uplink to the interfered-with system.

$$I_{External}(TX_{UE_k}^{BS_j}, RX^{victim}) = P_{UE_k}^{BS_j} \times CL_{External}(TX_{UE_k}^{BS_j}, RX^{victim}) \ / \ ACIR_{linear} \quad (14)$$

(Replace $ACIR_{linear}$ with FDR in case FDR is used.)

Where:

$P_{UE_k}^{BS_j}$: Transmission power of the k-th UE which is served by BS_j

$CL_{External}(TX_{UE_k}^{BS_j}, RX^{victim})$: Coupling loss from the k-th UE served by BS_j to the interfered-with receiver.

$I_{External}(TX_{UE_k}^{BS_j}, RX^{victim})$: Inter-system interference from the k-th UE served by BS_j to the interfered-with receiver.

The aggregate external-system interference is denoted by:

$$I_{External} = \sum_j \sum_k I_{External}(TX_{UE_k}^{BS_j}, RX^{victim}) \quad (15)$$

where:

$I_{External}$: The aggregate external system interference towards the interfered-with system.

Calculate impact on the interfered-with system from external interference. Calculation of the impact on non-IMT interfered-with system is outside the scope of this Recommendation and depends on the sharing scenario.

c. Continue to step 7.

4. Select IMT UL to as the interfered-with station.

a. Randomly select *x*% of the BS depending on system load

b. Calculate UL *C*/*I* for all "chosen" UEs in all cells.

Loop over all selected BSs from $j = 1$ to N_{cell} (the number of selected BSs in the system area).

Loop over all "chosen" UEs in selected BSs from $k = 1$ to *K*.

For the k-th "chosen" UE in the j-th cell (i.e. $UE_{j,k}$) its *C*/*I* is denoted by $\frac{C(j,k)}{I(j,k)}$

where:

$C(j,k)$ is the received power from $UE_{j,k}$, at the j-th BS

$$C(j,k) = P_{PUSCH}(j,k) \times pathCouplingLoss(UE_{j,k}, BS_j) \quad (16)$$

$I(j,k)$ is the interference power which consists of intra system interference (interference from UEs allocated to same resource blocks in other cells in own network) $I_{\mathrm{intra}}(j,k)$, and thermal noise N_t.

$$I(j,k) = I_{\mathrm{intra}}(j,k) + N_t \quad (17)$$

$$I_{\text{intra}}(j,k) = \sum_{l=1,l\neq j}^{N_{cell}} P_{PUSCH}(l,k) \times pathCouplingLoss(UE_{l,k}, BS_j) \tag{18}$$

$$N_t = 10\wedge((10\log_{10}(kT) + 10\log_{10}(bandwidth\ \ of\ n\,RBs) + NoiseFigure_{BS})/10) \tag{19}$$

where 10log$_{10}$(kT) is the noise power spectral density in dBm.

5. Add external interference Z_y, consisting of y interferers each with a power $P_{ext,y}$

If interference only occurs in one or few cells, main interference should be placed in an active cell (i.e. a cell with a selected BS).

Calculate externally interfered UL C/I=($\frac{C(j,k)}{I(j,k)}$) for all "chosen" UEs.

$C(j,k)$, $I_{\text{intra}}(j,k)$ and N_t are the same as in step 4.

$$I(j,k) = I_{\text{intra}}(j,k) + I_{external}(j,k) + N_t \tag{20}$$

$$I_{external}(j,k) = \sum_{m=1}^{y} P_{ext,m} \times pathCouplingLoss(Z_m, BS_j)\ \ /\ \ ACIR_{linear} \tag{21}$$

Used ACIR value should be calculated based on per UE allocated number of resource blocks. Replace $ACIR_{linear}$ with FDR in case FDR is used.

$$N_t = 10\wedge((10\log_{10}(kT) + 10\log_{10}(bandwidth\ \ of\ n\,RBs) + NoiseFigure_{BS})/10) \tag{22}$$

where 10log$_{10}$(kT) is the noise power spectral density in dBm.

6. Determine the throughput with and without external interference for each "chosen" UE with its C/I according to the link-to-system level mapping.

7. Collect statistics.

4 Implementation of IMT User Equipment (UE) power control

Power control is a significant technical feature of IMT systems. The uplink cell capacity in OFDMA-based systems is constrained by interference levels from other UEs. UE power output levels are adjusted to maintain minimum interference and are adjusted to ensure cell edge coverage. Power control can be combined with frequency-domain resource allocation strategies to enhance cell edge performance as well as improve spectral efficiency.

It should be noted that as UE transmitter output power may be lower than the maximum transmitter output power in the transmitting frequency band, the average out-of-band emission (OOBE) level would be lower than the specified OOBE level.

4.1 Power control algorithm

For IMT-Advanced systems, UE power control algorithm to be used in sharing studies is as follows:

$$P_{\text{PUSCH}}(i) = \min\left(P_{\text{CMAX}}, 10\log_{10}(M_{\text{PUSCH}}(i)) + P_{\text{O\_PUSCH}}(j) + \alpha(j)\cdot PL\right) \tag{23}$$

where:

- P_{PUSCH} transmit power of the terminal in dBm
- P_{CMAX} maximum transmit power in dBm
- M_{PUSCH} number of allocated RBs
- P_{0_PUSCH} power per RB used target value in dBm
- α balancing factor for UEs with bad channel and UEs with good channel
- PL path loss in dB for the UE from its serving BS.

It is expected that for IMT-2020 systems UE power control algorithm could be similar to that used for IMT-Advanced networks.

5 Implementation of IMT Base Station (BS) and User Equipment (UE) Beamforming Antenna Pattern

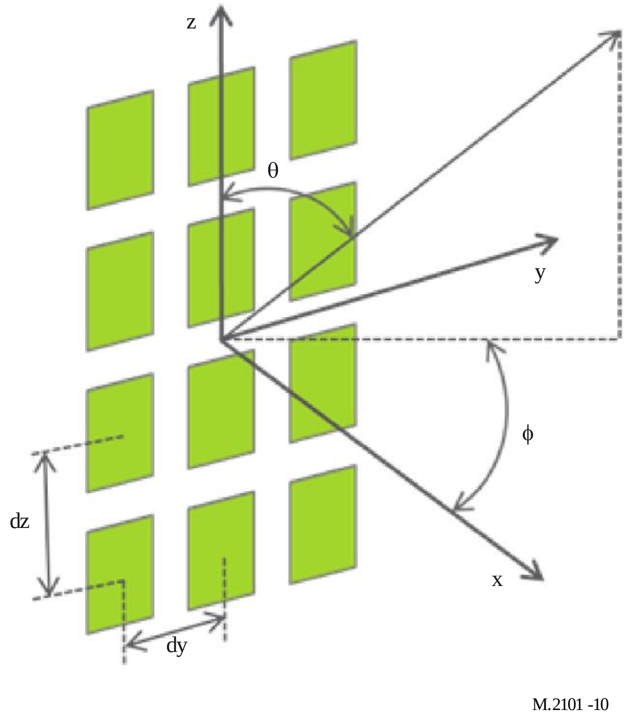
Recommendation ITU-R F.1336 has been used in the past when conducting sharing studies (reference to Report ITU-R M.2292) and may be feasible for some IMT scenarios. The majority of IMT-2020 systems will use beamforming especially at higher frequencies.

The beamforming antenna is based on an antenna array and consists of a number of identical radiating elements located in the yz-plane with a fixed separation distance (e.g. $\lambda/2$), all elements having identical radiation patterns and “pointing” (having maximum directivity) along the x-axis. A weighting function is used to direct the beam in various directions. Total antenna gain is the sum (logarithmic scale) of the array gain and the element gain. Such a model is described in 3GPP TR 37.842 and section 5.4.4.1 of 3GPP TR 37.840 as follows.

The θ and φ definition is based on the coordinate system are illustrated in Fig. 10.

FIGURE 10

Antenna Model Geometry, θ: elevation, range from 0 to 180 degree
φ: Azimuth, range from −180 to 180 degree



The radiation elements are placed uniformly along the vertical z-axis in the Cartesian coordinate system. The x-y plane denotes the horizontal plane. The elevation angle of the signal direction is denoted as θ (defined between 0° and 180°, with 90° representing perpendicular angle to the array antenna aperture). The azimuth angle is denoted as φ (defined between −180° and 180°).

One difference between a passive antenna system (e.g. based on Recommendation ITU-R F.1336) and an active Advanced Antenna System (AAS) is that for the AAS, the unwanted (out of block) emission will see a different antenna behaviour compared to the wanted (in block) emission.

An IMT system using an AAS will actively control all individual signals being fed to individual antenna elements in the antenna array in order to shape and direct the antenna emission diagram to a wanted shape, e.g. a narrow beam towards a user. In other words, it creates a correlated wanted emission from the antenna. The unwanted signal, caused by transmitter OOB modulation, intermodulation products and spurious emission components will not experience the same correlated situation from the antenna and will have a different emission pattern. A non-correlated AAS has an antenna emission pattern similar to a single antenna element.

In an adjacent frequency band situation with IMT as the interfering system, the antenna pattern for the unwanted emission can be assumed to have a similar antenna pattern as a single antenna element. For emissions of the IMT system inside the channel bandwidth the composite antenna pattern needs to be simulated.

In an adjacent frequency band situation with IMT as the interfered-with system when adjacent channel interference is calculated antenna pattern can be assumed to have a similar antenna pattern as a single antenna element. For interference into the channel bandwidth of the IMT system the composite antenna pattern needs to be simulated.

The AAS antenna array model is determined by array element pattern, array factor and signals applied to the array system. The element pattern and composite antenna pattern are described in the following sections.

5.1 Element pattern

TABLE 3

Element pattern for antenna array model

Horizontal Radiation Pattern	$A_{E,H}(\varphi) = -\min\left[12\left(\frac{\varphi}{\varphi_{3dB}}\right)^2, A_m\right] dB$
Horizontal 3dB bandwidth of single element / deg (φ_{3dB})	Input parameter
Front-to-back ratio: A_m and SLA_v	Input parameter
Vertical Radiation Pattern	$A_{E,V}(\theta) = -\min\left[12\left(\frac{\theta - 90}{\theta_{3dB}}\right)^2, SLA_v\right]$ dB
Vertical 3dB bandwidth of single element / deg (θ_{3dB})	Input parameter
Single element pattern	$A_E(\varphi,\theta) = G_{E,\max} - \min\{-\lfloor A_{E,H}(\varphi) + A_{E,V}(\theta)\rfloor, A_m\}$
Element gain (dBi), $G_{E,\max}$	Input parameter

5.2 Composite antenna pattern

Table 4 illustrates the derivation of the composite antenna pattern, $A_A(\theta,\varphi)$. $A_A(\theta,\varphi)$ is the resulting beamforming antenna pattern from logarithmic sum of the array gain, $10\log_{10}\left(\left|\sum_{m=1}^{N_H}\sum_{n=1}^{N_V} w_{i,n,m}\cdot v_{n,m}\right|^2\right)$, and the element gain $A_E(\theta,\varphi)$. The composite pattern for the base station antenna should be used where the array serves one or more UEs with one or more beams, with each beam indicated by the parameter *i*.

TABLE 4

Composite antenna pattern for BS and UE beam forming

Configuration	Multiple columns ($N_V \times N_H$ elements)
Composite array radiation pattern in dB $A_A(\theta,\varphi)$	For beam i: $A_{A,Beami}(\theta,\varphi) = A_E(\theta,\varphi) + 10\log_{10}\left(\left\lvert \sum_{m=1}^{N_H} \sum_{n=1}^{N_V} w_{i,n,m} \cdot v_{n,m} \right\rvert^2\right)$ the super position vector is given by: $v_{n,m} = \exp\left(\sqrt{-1} \cdot 2\pi\left((n-1) \cdot \frac{d_V}{\lambda} \cdot \cos(\theta) + (m-1) \cdot \frac{d_H}{\lambda} \cdot \sin(\theta) \cdot \sin(\varphi)\right)\right),$ $n = 1,2,\ldots N_V; m = 1,2,\ldots N_H;$ the weighting is given by: $w_{i,n,m} = \frac{1}{\sqrt{N_H N_V}} \exp\left(\sqrt{-1} \cdot 2\pi\left((n-1) \cdot \frac{d_V}{\lambda} \cdot \sin(\theta_{i,etilt}) - (m-1) \cdot \frac{d_H}{\lambda} \cdot \cos(\theta_{i,etilt}) \cdot \sin(\varphi_{i,escan})\right)\right)$
Antenna array configuration (Row × Column)	Input parameter
Horizontal radiating element spacing d/λ	Input parameter
Vertical radiating element spacing d/λ	Input parameter
Down-tilt angle (degrees)	Input parameter

6 Implementation of IMT traffic information

For most Monte-Carlo simulation studies involving advanced IMT systems, a full buffered traffic model is assumed. This is equivalent to assuming that the base stations are always transmitting/receiving using all resource blocks. Report ITU-R M.2241 mentions that this is not the case in deployed OFDM networks because transmitting 100% of the frequency resource blocks 100% of the time leads to saturation of the cell and service failure for many of the users. Thus base stations transmit using only part of the available resource blocks most of the time.

Guidance to better account for real IMT network behaviour, whether the IMT system is the interfered-with system or acts as an aggregated interferer are described in this Recommendation (§ 7).

Loading in an IMT network depends on a number of factors such as user behaviour, applications and deployment scenarios. For simplification, network load is modelled by statistically varying which fully loaded base stations are simultaneously transmitting and/or the number of them. This has been presented as activity factor of base stations in relevant ITU-R documentation, such as Report ITU-R M.2292. Modelling of the IMT network load may depend on the sharing scenario. For example, the modelling of the network load in interference modelling may depend on factors such as the size of the area over which interference is aggregated.

7 Determination of aggregate interference

The simulation set up described in § 3 of this Recommendation calculates the aggregate interference from several base stations and/or UEs. Thus, it can be concluded that the simulator always inherently calculates the aggregate interference from IMT network to the interfered-with system. However, depending on the co-existence scenario the issues mentioned below should also be considered:

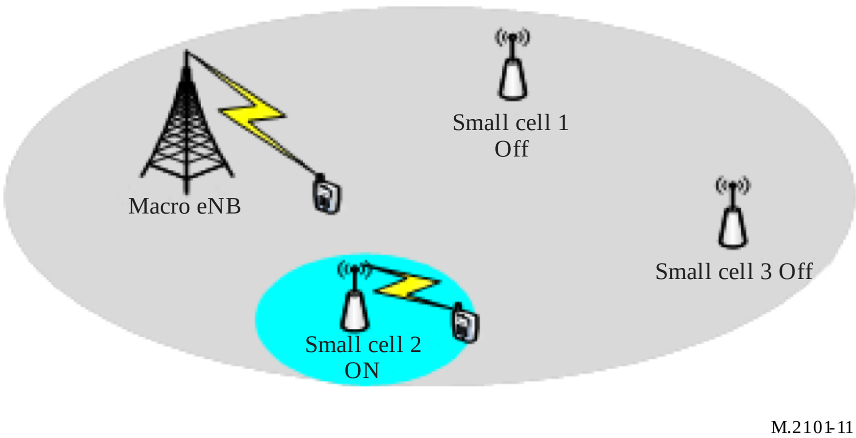
– BSs are modelled as transmitting with full power or not transmitting at all with a load probability, i.e. *x*% of the BSs are randomly selected to transmit and the rest do not transmit. See § 6. The value of *x* can either be a single number or selected randomly from a range in each snapshot.

– In those cases when sharing studies require simulations with a very large number of IMT stations, the direct implementation of the modelling described above may be excessively time-consuming. In those cases, the statistics of IMT system emissions could be modelled and collected from a representatively large segment of the IMT network. The collected statistics from this segment may then be used to calculate interference from multiple segments that have equivalent interference characteristics taking into account the variation of IMT system deployment scenarios throughout large regions. Care should be taken to reflect the variation in interference angle of departure and arrival at the interfered-with system given the geography of the large area. It should be emphasized that any simplification in the implementation should not lead to deviation in the resulting IMT system emissions statistics compared to direct application of this methodology.

– The IMT small cells can be turned on/off in large time scales, semi-statically or dynamically, which may affect load probability. This might include inclusion of time in the simulation process. On/off scheme can reduce the interference to other neighboring small cells or other systems when using the same or adjacent frequency channel (see Fig. 11). In addition, small cell on/off schemes may also provide benefits in terms of energy savings. Relevant detailed technology information can be found in 3GPP RP-130811 [3], 3GPP TR 36.873 [4], 3GPP TR36.897 [5] and 3GPP TR 36.872 [1].

FIGURE 11

Small cell on/off scheme



– If TDD operation is to be simulated, the base station downlink transmission occurs only part of the time, which will reduce the average base station power over a frame. However, this effect is not taken into account in the modelling described in this Recommendation.

Network deployment will be more flexible in the future because of variety of service requirements; high data rate traffic mainly occurs in discrete hot-spot regions, therefore, partial area interference may be considered in aggregate interference calculation.

8 Demonstration of interim results of IMT modelling

In modelling IMT systems, it is probable that the same study performed by different parties could initially produce different results. In order to be able to compare simulator implementations of the IMT system, it is possible to use some intermediate results. Some examples of such parameters are:

– Transmit power distribution.

– Internal and external interference distribution.

– SINR distribution.

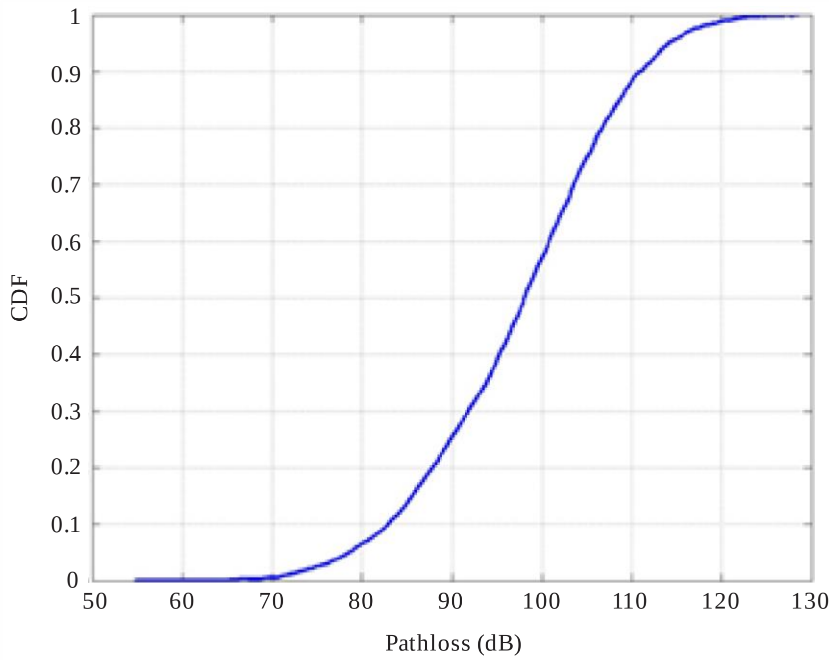
– Received power distribution.

– Path coupling loss distribution (this includes Tx and Rx antenna gains, propagation loss and fading, etc.).

Generation of at least two of the interim results listed above is recommended. The following Fig. 12 shows an illustrative example interim result for path loss distribution. Such interim results should be considered together with the full set of input parameters. Other results could also be generated in a similar way.

FIGURE 12

Example of path loss distribution from simulation of an IMT network



M.2101-12

9 References

[1] 3GPP TR 36.872 V12.1.0, Small cell enhancements for E-UTRA and E-UTRAN (Release 12).

[2] 3GPP TR 25.942 V10.0.0, Radio Frequency (RF) system scenarios (Release 10).

[3] 3GPP RP-130811, 3GPP Work Item Description, Study on 3D-channel model for Elevation Beamforming and FD-MIMO studies for LTE.

[4] 3GPP TR 36.873 V12.0.0, Study on 3D channel model for LTE (Release 12).

[5] 3GPP TR 36.897 V0.3.1, Elevation Beamforming/Full-Dimension (FD) MIMO for LTE (Release 13).

[6] 3GPP TS 36.104 V12.7.0, Base Station (BS) radio transmission and reception (Release 12).

[7] 3GPP TS 36.101 V12.7.0, User Equipment (UE) radio transmission and reception (Release12).

[8] H. Houas, Y. Louet, E. Fournier and Y. Maigron, *Distribution of microcells for cellular mobile networks, IEEE VTC Nanjing, 15-18th May 2016*.

Attachment 1
to Annex 1

Considerations on parameters driving the Variance Gamma (Bessel) distribution for the micro BS locations

When distributing small cells locations within a given Macro cell area,

1. an (average) number of clusters containing these small cells has to be set within this area. This parameter can be derived by initially considering a map of macro (hexagonal shaped) base stations on which a cluster (of small cells) could be positioned. It corresponds to λ_p.
2. An (average) number of small cells within each cluster should be assumed. It corresponds to λ_o.
3. [1][5] indicates that γ varies in the range [−0.45,-0.3]. It is then recommended to work with the min/max values of this range.
4. the last parameter, ω, needs further consideration to be derived in an appropriate way:
   i. **Stage 1:** another parameter, easier to set because it reflects a physical meaning is the (average) radius of the cluster, called *R*. This could be understood as the radius of the (assumed disk) area where the small cells are (likely, with a high probability) located to provide the expected application for the user. This radius of an area also assumes a center that corresponds to the center of the cluster.
   ii. **Stage 2:** As *R* cluster radius is originally derived from cluster radius R-function[6] with the input parameters ω and γ and that is γ known while ω is unknown, it is then possible to build up a look-up table that associates for each couple (γ, *R*) the unknown scale ω.

These four parameters finally enable to draw out a random set of NSVGP samples, recalling that the process is constructed by first generating a Poisson point process of "parent" points (i.e. Cluster centres) with intensity λ_p. Then each parent point is replaced by a random cluster of points, the number of points in each cluster being random with a Poisson (λ_o) distribution, and the points being placed independently and uniformly according to a Variance Gamma kernel. The Variance Gamma Kernel is defined in accordance with γ and ω.

Having described the parameters driving this distribution, it is then possible to statistically describe (through probability density function pdf) Variance Gamma Bessel distribution. Noting that the offspring points within each cluster are generated following a normal variance-mean mixture distribution, i.e. with normal distribution mixed with gamma distribution whose probability density function (pdf) *f* is: $f(x;k,\theta) = \frac{x^{k-1}e^{-\frac{x}{\theta}}}{\Gamma(k)\theta^k}$

where $\Gamma(\mathrm{k}) = \frac{e^{-\gamma k}}{k}\prod_{n=1}^{+\infty}\left(1+\frac{k}{n}\right)^{-1} e^{\frac{k}{n}}$ and $\gamma = \lim_{n\to\infty}\left(\sum_{k=1}^{n}\frac{1}{k} - \ln(n)\right)$,

one could notice that θ and *k* are linked to the other parameters described in the previous sections by the following formula: $k = \gamma + 1$ and $\theta = \frac{1}{2\omega^2}$.

---

[5] *Distribution of microcell base stations within cellular networks*, IEEE VTC May 2016, Nanjing.

[6] From R-language (spatstat package, http://spatstat.github.io).

Attachment 2 to Annex 1

Wrap-around Technique

To analyse the behaviour of a cellular network without inducing any artefacts due to boundary effects limitations, it is necessary to consider an infinite cellular network. One way to achieve this is to use a “wrap-around” technique where the original cell cluster is wrap-around to form a toroidal surface.

To illustrate the nature of the wrap-around cell structure, a cluster of 19 base station sites (57 cells) is repeated six times as shown in Fig. 13. Note that the original cell cluster remains in the centre while the six clusters evenly surround this centre set.

In the wrap-around model considered, the signal or interference from any mobile station to a given cell is treated as if that mobile station is in the original cell cluster and the base station in any of the seven clusters. The path coupling loss from any mobile station to any base station can be obtained as follows:

1. Define a coordinate system such that the center of cell 0 is at (0,0).
2. The path distances and angles used to compute the path losses and antenna gains of a mobile station at (x,y) to a base station at (a,b) are:

   Distance between (x,y) and (a,b);

   Distance between (x,y) and $(a+3.5*D, b+1.5*\sqrt{3}*D)$;

   Distance between (x,y) and $(a-0.5*D, b+2.5*\sqrt{3}*D)$;

   Distance between (x,y) and $(a-4*D, b+\sqrt{3}*D)$;

   Distance between (x,y) and $(a-3.5*D, b-1.5*\sqrt{3}*D)$;

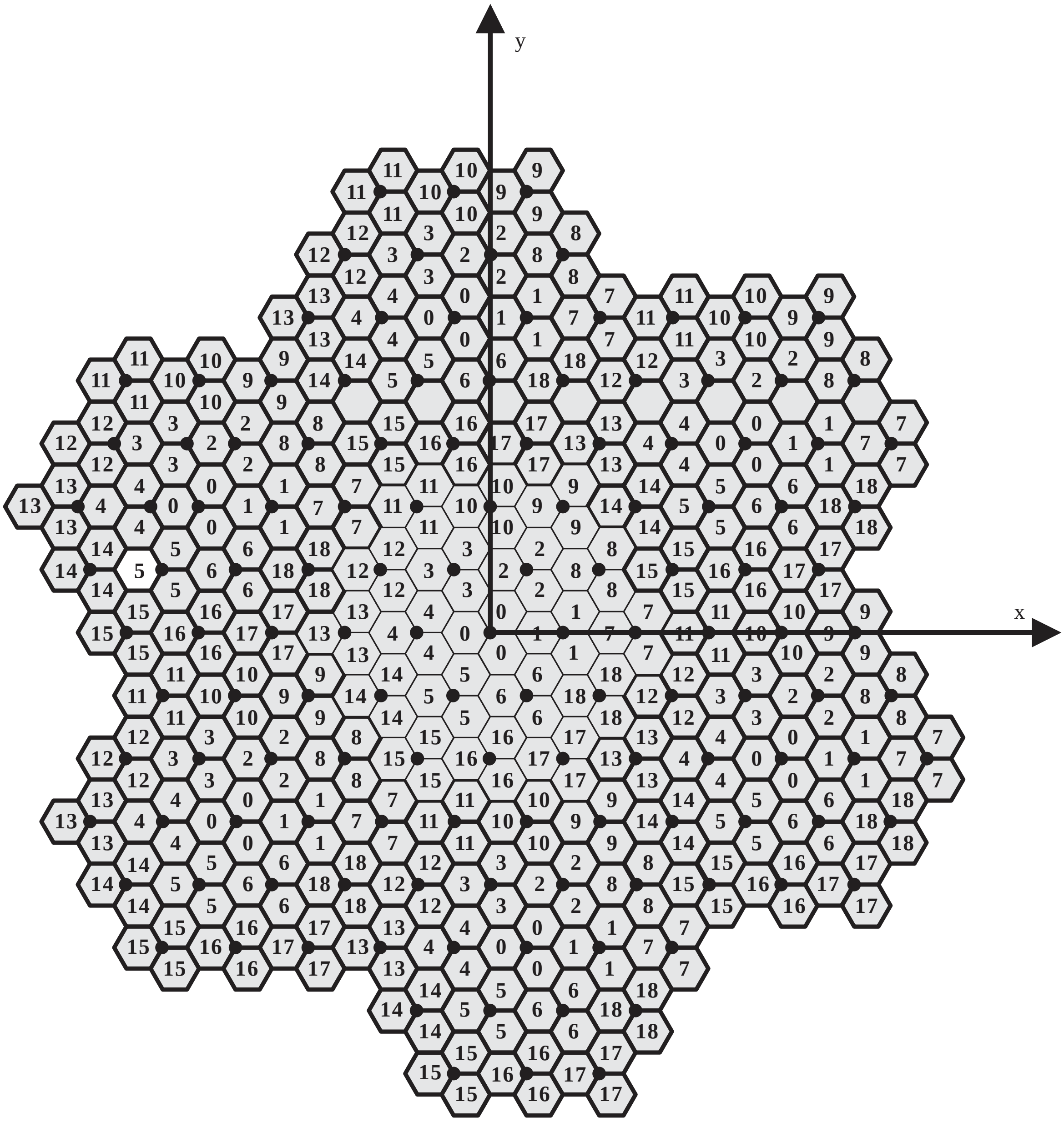
   Distance between (x,y) and $(a+0.5*D, b-2.5*\sqrt{3}*D)$;

   Distance between (x,y) and $(a+4*D, b-\sqrt{3}*D)$,

   where D is the base station to base station inter-site distance.
3. Coupling loss values (max{propagation loss + fading + antenna gains , MCL}) are calculated for the above path distances / angles and the minimum value is selected to be used for the simulation snapshot.

FIGURE 13

Wrap-around with '7' clusters of 19 base station sites (57 cells) showing the toroidal nature of the wrap-around surface



M.2101-13