Project	**IEEE 802.16 Broadband Wireless Access Working Group <http://ieee802.org/16>**
Title	**Draft IEEE 802.16m Evaluation Methodology Document**
Date Submitted	**2007-03-05**
Source(s)	Sassan Ahmadi Roshni M. Srinivasan Intel Corporation Hokyu Choi Jeongho Park Jaeweon Cho DS Park Samsung Electronics Louay Jalloul Beceem Communications	sassan.ahmadi@intel.com roshni.m.srinivasan@intel.com choihk@samsung.com jeongho.jh.park@samsung.com jaeweon.cho@samsung.com dspark@samsung.com jalloul@beceem.com
Re:	Call for contributions regarding P802.16m project, 1/22/2007
Abstract	This document contains proposed evaluation methodology for IEEE 802.16m technical proposals.
Purpose	For discussion and approval by TGm
Notice	
Release	
Patent Policy and Procedures	

Acknowledgements

The editors would like to acknowledge technical contributions from the following individuals to the current document and would like thank them for reviewing the content:

Name	Company
Ali Koc	Intel Corporation
Apostolos Papathanassiou	Intel Corporation
Assi Jakoby	Intel Corporation
Ayelet Doron	Intel Corporation
Belal Hamzeh	Intel Corporation
Clark Chen	Intel Corporation
Dov Andelman	Intel Corporation
Hannah Hyunjeong	Intel Corporation
Hongming Zheng	Intel Corporation
Hua Yang	Intel Corporation
Hujun Yin	Intel Corporation
Jie Hui	Intel Corporation
Minnie Ho	Intel Corporation
Muthaiah Venkatachalam	Intel Corporation
Nageen Himayat	Intel Corporation
Roshni Srinivasan	Intel Corporation
Sassan Ahmadi	Intel Corporation
Shailender Timiri	Intel Corporation
Shantidev Mohanty	Intel Corporation
Shilpa Talwar	Intel Corporation
Yang-seok Choi	Intel Corporation
Yuval Lomnitz	Intel Corporation
Hokyu Choi	Samsung Electronics

Table of Contents

List of Figures

List of Tables

Abbreviations and Acronyms

3GPP	3G Partnership Project
3GPP2	3G Partnership Project 2
AAS	Adaptive Antenna System also Advanced Antenna System
ACK	Acknowledge
AES	Advanced Encryption Standard
AG	Absolute Grant
AMC	Adaptive Modulation and Coding
A-MIMO	Adaptive Multiple Input Multiple Output (Antenna)
ASM	Adaptive MIMO Switching
ARQ	Automatic Repeat reQuest
ASN	Access Service Network
ASP	Application Service Provider
BE	Best Effort
CC	Chase Combining (also Convolutional Code)
CCI	Co-Channel Interference
CCM	Counter with Cipher-block chaining Message authentication code
CDF	Cumulative Distribution Function
CINR	Carrier to Interference + Noise Ratio
CMAC	block Cipher-based Message Authentication Code
CP	Cyclic Prefix
CQI	Channel Quality Indicator
CSN	Connectivity Service Network
CSTD	Cyclic Shift Transmit Diversity
CTC	Convolutional Turbo Code
DL	Downlink
DOCSIS	Data Over Cable Service Interface Specification
DSL	Digital Subscriber Line
DVB	Digital Video Broadcast
EAP	Extensible Authentication Protocol
EESM	Exponential Effective SIR Mapping
EIRP	Effective Isotropic Radiated Power
ErtVR	Extended Real-Time Variable Rate
FBSS	Fast Base Station Switch
FCH	Frame Control Header
FDD	Frequency Division Duplex
FFT	Fast Fourier Transform
FTP	File Transfer Protocol
FUSC	Fully Used Sub-Channel
H-ARQ	Hybrid Automatic Repeat reQuest

HHO	Hard Hand-Off
HMAC	keyed Hash Message Authentication Code
HO	Hand-Off
HTTP	Hyper Text Transfer Protocol
IE	Information Element
IEFT	Internet Engineering Task Force
IFFT	Inverse Fast Fourier Transform
IR	Incremental Redundancy
ISI	Inter-Symbol Interference
LDPC	Low-Density-Parity-Check
LOS	Line of Sight
MAC	Media Access Control
MAI	Multiple Access Interference
MAN	Metropolitan Area Network
MAP	Media Access Protocol
MBS	Multicast and Broadcast Service
MDHO	Macro Diversity Hand Over
MIMO	Multiple Input Multiple Output (Antenna)
MMS	Multimedia Message Service
MPLS	Multi-Protocol Label Switching
MS	Mobile Station
MSO	Multi-Services Operator
NACK	Not Acknowledge
NAP	Network Access Provider
NLOS	Non Line-of-Sight
NRM	Network Reference Model
nrtPS	Non-Real-Time Packet Service
NSP	Network Service Provider
OFDM	Orthogonal Frequency Division Multiplex
OFDMA	Orthogonal Frequency Division Multiple Access
PER	Packet Error Rate
PF	Proportional Fair (Scheduler)
PKM	Public Key Management
PUSC	Partially Used Sub-Channel
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase Shift Keying
RG	Relative Grant
RR	Round Robin (Scheduler)
RRI	Reverse Rate Indicator
RTG	Receive/transmit Transition Gap
rtPS	Real-Time Packet Service
RUIM	Removable User Identify Module

SDMA	Space (or Spatial) Division (or Diversity) Multiple Access
SF	Spreading Factor
SFN	Single Frequency Network
SGSN	Serving GPRS Support Node
SHO	Soft Hand-Off
SIM	Subscriber Identify Module
SINR	Signal to Interference + Noise Ratio
SISO	Single Input Single Output (Antenna)
SLA	Service Level Agreement
SM	Spatial Multiplexing
SMS	Short Message Service
SNIR	Signal to Noise + Interference Ratio
SNR	Signal to Noise Ratio
S-OFDMA	Scalable Orthogonal Frequency Division Multiple Access
SS	Subscriber Station
STC	Space Time Coding
TDD	Time Division Duplex
TEK	Traffic Encryption Key
TTG	Transmit/receive Transition Gap
TTI	Transmission Time Interval
TU	Typical Urban (as in channel model)
UE	User Equipment
UGS	Unsolicited Grant Service
UL	Uplink
UMTS	Universal Mobile Telephone System
USIM	Universal Subscriber Identify Module
VoIP	Voice over Internet Protocol
VPN	Virtual Private Network
VSF	Variable Spreading Factor
WiFi	Wireless Fidelity
WAP	Wireless Application Protocol
WiBro	Wireless Broadband (Service)
WiMAX	Worldwide Interoperability for Microwave Access

Definitions

To be added later

References

[1] Guidelines for Evaluation of Radio Transmission Technologies for IMT-2000, "Recommendation ITU-R M.1225," 1997

[2] 3GPP2 C.R1002-0 1.0, "CDMA2000 Evaluation Methodology", January 2005.

[3] Recommendation ITU-R M.1225, "Guidelines for Evaluation of Radio Transmission Technologies for IMT-2000", 1997.

[4] 3GPP-3GPP2 Spatial Channel Ad-hoc Group, "Spatial Channel Model Text Description," V7.0, August 19, 2003

[5] RUNCOM, "Coverage capacity simulations for OFDMA PHY in ITU-T channel models, " IEEE C802.16d-03/78r1, November, 2003

[6] RUNCOM, "Coverage simulation for OFDMA PHY mode," IEEE C8021.6e-03/22r1 Sony, Intel, "TGn Sync TGn Proposal MAC Simulation Methodology", IEEE 802.11-04/895r2, November 2004.

[7] Sony, Intel, "TGn Sync TGn Proposal MAC Simulation Methodology", IEEE 802.11-04/895r2, November 2004.

[8] ST Micro-Electronics "Time Correlated Packet Errors in MAC Simulations", IEEE Contribution, 802.11-04-0064-00-000n, Jan. 2004.

[9] Atheros, Mitsubishi, ST Micro-Electronics and Marvell Semiconductors, "Unified Black Box PHY Abstraction Methodology", IEEE Contribution 802.11-04/0218r1, March 2004.

[10]3GPP TR 25.892 V2.0.0 "Feasibility Study for OFDM for UTRAN enhancement,"

[11]WG5 Evaluation Ad-hoc Group, "1x EV-DV Evaluation Methodology – Addendum (V6)," July 25, 2001

[12]Ericsson, "System level evaluation of OFDM- further considerations", TSG-RAN WG1 #35, R1-03-1303, November, 2003

[13]Nortel, "Effective SIR Computation for OFDM System-Level Simulations," TSG-RAN WG1 #35, R03-1370, November 2003.

[14]Nortel "OFDM Exponential Effective SIR Mapping Validation, EESM Simulation Results for System-Level Performance Evaluations," 3GPP TSG-RAN1 Ad Hoc, R1-04-0089, January, 2004.

[15]K. Brueninghaus et. al. "Link performance models for system level simulations of broadband radio access," IEEE PIMRC, 2005.

[16]L. Wan, S. Tsai, M. Almgren, "A fading insensitive performance metric for a unified link quality model," WCNC, 2006.

[17]DoCoMo, Ericsson, Fujitsu, Mitsubishi Electric, NEC, Panasonic, Sharp, Toshiba Corporation, R1-060987, "Link adaptation schemes for single antenna transmissions in the DL, 3GPP-LTE WG1 meeting #44-bis, Athens, March 2006.

[18]P. Barford and M Crovella, "Generating Representative Web Workloads for Network and Server Performance Evaluation" In Proc. ACM SIGMETRICS International Conference on Measurement and Modeling of Computer Systems, pp. 151-160, July 1998.

[19]S. Deng. "Empirical Model of WWW Document Arrivals at Access Link." In Proceedings of the 1996 IEEE International Conference on Communication, June 1996

[20]R. Fielding, J. Gettys, J. C. Mogul, H. Frystik, L. Masinter, P. Leach, and T. Berbers-Lee, "Hypertext Transfer Protocol - HTTP/1.1", RFC 2616, HTTP Working Group, June 1999. ftp://ftp.Ietf.org/rfc2616.txt.

[21]B. Krishnamurthy and M. Arlitt, "PRO-COW: Protocol Compliance on the Web", Technical Report 990803-05-TM, AT&T Labs, August 1999, http://www.research.att.com/~bala/papers/procow-1.ps.gz. 29 30 31 32 33 34 35 36 37

[22]B. Krishnamurthy, C. E. Wills, "Analyzing Factors That Influence End-to-End Web Performance", http://www9.org/w9cdrom/371/371.html

[23]H. K. Choi, J. O. Limb, "A Behavioral Model of Web Traffic", Proceedings of the seventh International Conference on Network Protocols, 1999 (ICNP '99), pages 327-334.

[24]F. D. Smith, F. H. Campos, K. Jeffay, D. Ott, "What TCP/IP Protocol Headers Can Tell Us About the Web", Proc. 2001 ACM SIGMETRICS International Conference on Measurement and Modeling of Computer Systems, pp. 245-256, Cambridge, MA June 2001.

[25]J. Cao, William S. Cleveland, Dong Lin, Don X. Sun., "On the Non-stationarity of Internet Traffic", Proc. ACM SIGMETRICS 2001, pp. 102-112, 2001.

[26]K. C. Claffy, "Internet measurement and data analysis: passive and active measurement", http://www.caida.org/outreach/papers/Nae/4hansen.html.

[27]3GPP TR 25.896 “3GPP TSG RAN Feasibility Study for Enhanced Uplink for UTRA FDD (Release 6)”, 2004-03

[28]RFC 3267 - Real-Time Transport Protocol (RTP) Payload Format and File Storage Format for the Adaptive Multi-Rate (AMR) and Adaptive Multi-Rate Wideband (AMR-WB) Audio Codecs

[29]3GPP2/TSG-C.R1002, “1xEV-DV Evaluation Methodology (V14)”, June 2003

[30]IEEE P 802.20™ PD-09 Version 1.0, “802.20 Evaluation Criteria – version 1.0,” September 23, 2005

[31]WINNER Project, IST-2003-507581 WINNER D1.3 version 1.0, “Final usage scenarios.”

[32] 3GPP TSG-RAN1#48 R1-070674, LTE physical layer framework for performance verification, Orange, China Mobile, KPN, NTT DoCoMo, Sprint, T-Mobile, Vodafone, Telecom Italia, February 2007.

1 Introduction

The objective of this evaluation methodology is to define baseline link-level and system-level simulation models and associated parameters that shall be used in the evaluation and comparison of technology proposals for IEEE 802.16m. Proponents of any technology proposal using this methodology shall follow the evaluation methods defined in this document and report the results using the metrics and the format that are specified in Appendix A.

Evaluation of system performance of a mobile broadband wireless access technology requires system simulation that accurately captures the dynamics of a multipath fading environment and the architecture of a packet-switched air-interface. The main simulation components are illustrated in Figure 1-1.

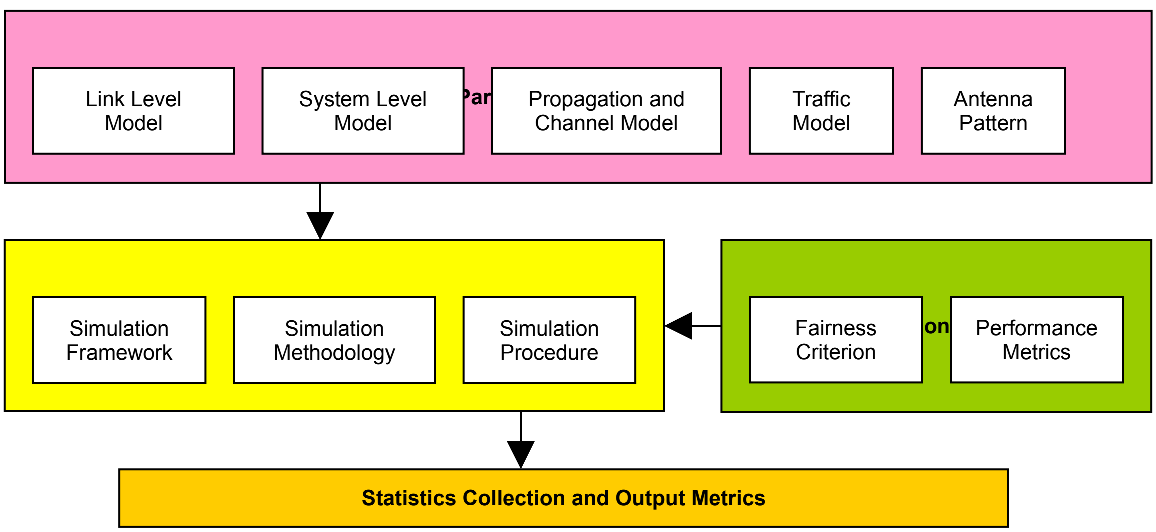

Figure 1-1: Simulation components

System level simulations shall capture the important characteristics of the wireless channel in a cellular deployment scenario. The slow fading characteristics are captured through the path loss model and the variance of the log-normal shadowing. The fast fading effects are captured by the frequency-selective fading resulting from multipath and the time-selective fading resulting from the mobility model.

2 Duplex Schemes

Both TDD and FDD duplex schemes shall be supported. Link-level and system-level simulation results shall be provided for both TDD and FDD duplex schemes. The configuration of the two schemes for link-level and system-level simulations is identical except for the following attributes:

i] Channel model

In TDD duplex scheme, the DL and UL channels are reciprocal. One channel instance can be used in both DL and UL. In FDD duplex scheme, DL and UL channels are different. One wideband channel shall be generated and the DL and UL channel responses correspond to their respective channel spectrum.

ii] Propagation model

In TDD duplex scheme, the DL and UL have the same propagation pattern. In FDD mode, DL and UL the same propagation model can still be used with different carrier frequency. The shadow fading is 100% correlated.

iii] TTG/RTG gap (TX/RX switching point) overhead

In TDD mode, TTG/RTG gap should be counted as an additional layer 1 overhead.

iv] DL/UL frame alignment

In TDD mode, the DL and UL alternates in time domain. The timing of transmission and feedback (ACK/NACK and CQI) is mainly determined by the DL/UL and UL/DL switching points. In FDD mode, the DL and UL are concurrent in time. The timing of transmission and feedback is mainly determined by the subframe size and processing delay. The DL and UL frames should have appropriate offset to have desired timing for transmission and feedback. The frame offset should be determined by frame structure design.

v] TDD DL/UL ratio

In TDD mode, the DL/UL ratio can be flexible. At most two ratios should be considered (one is equal partition 1:1). The timing relation of transmission and feedback may be different for different DL/UL ratios.

3 System-Level Setup

Antenna Pattern

The antenna pattern used for each sector is specified as:

$$A \quad \min 12 \left(\frac{\quad}{_{3\,dB}}\right)^{2}, A_m \quad , \qquad (3.1\text{-}1)$$

Where $180 \quad 180$, and min [.] denotes the minimum function, $_{3dB}$ is the 3dB beam width (corresponding to $_{3dB}$ = 70 degrees), and A_m= 20 dB is the maximum attenuation.

Antenna Orientation

The antenna bearing is defined as the angle between the main antenna lobe center and a line directed due east given in degrees. The bearing angle increases in a clockwise direction. Figure 3-2 shows an example of the 3-sector 120-degree center cell site, with Sector 1 bearing angle of 330 degrees. Figure 3-3 shows the orientation of the center cell (target cell) hexagon and its three sectors corresponding to the antenna bearing orientation proposed for the simulations. The main antenna lobe center directions each point to the sides of the hexagon. The main antenna lobe center directions of the 18 surrounding cells shall be parallel to those of the center cell. Figure 3-3 also shows the orientation of the cells and sectors in the two tiers of cells surrounding the central cell.

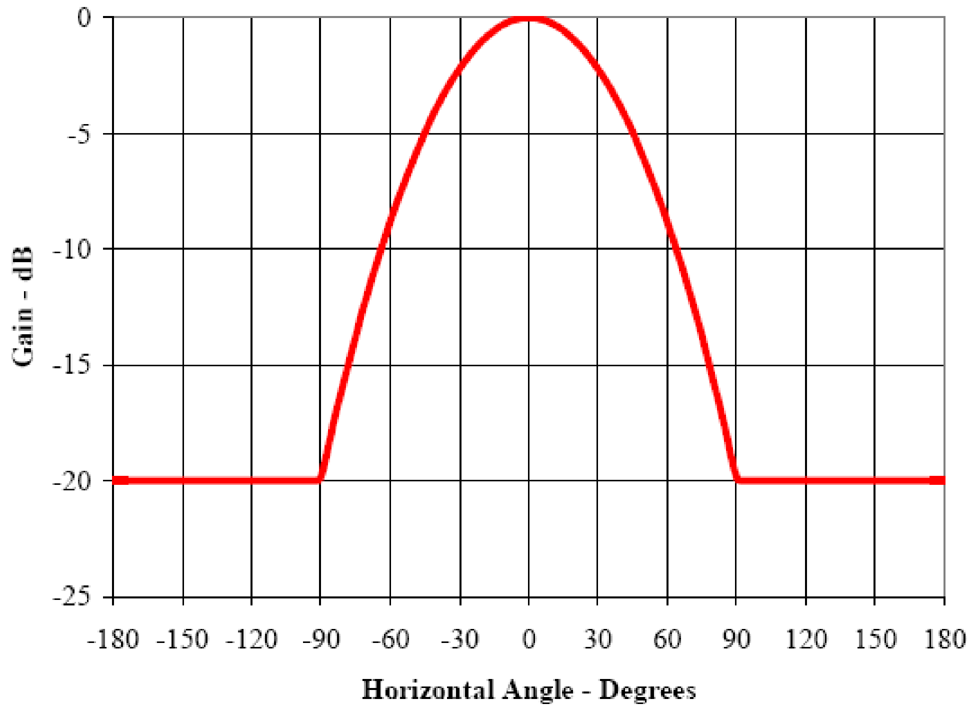

Figure 3-2: Antenna Pattern for 3-Sector Cells

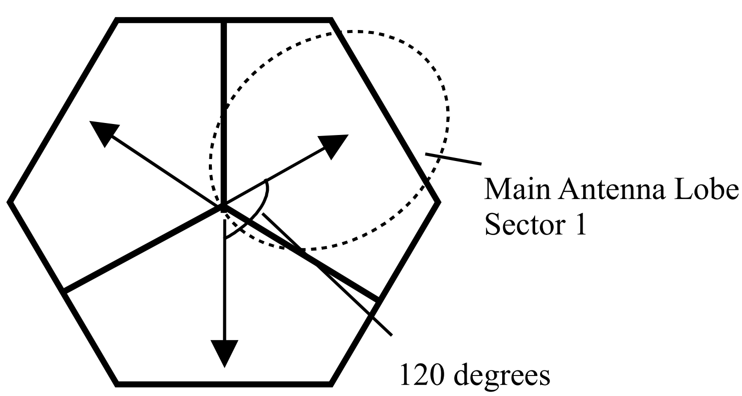

Figure 3-3: Centre cell antenna bearing orientation diagram

Baseline System-Level Simulation Assumptions

The following tables summarize the baseline assumptions for the system-level simulations for the downlink and uplink. These assumptions will be further clarified and explained in the next sections.

Topic	Baseline for simulation, modelling assumptions
Basic transmission scheme	Parameters as in table (include reference)
Basic modulation	QPSK, 16QAM, 64QAM
Duplexing scheme	TDD and FDD
Resource block definition	TBD
Data Multiplexing	Data transmissions: OFDMA Control transmissions: OFDMA
Downlink pilot structure	TBD
Receiver Structure	MMSE
Data Channel coding	Convolutional turbo coding
Multiple antenna configuration	2x2 antenna configuration (reference) Overhead calculations for uplink feedback should be shown Downlink overhead should be described and taken into account Channel estimation – should ideally be modelled or at least calculations showing the impact presented Control channels – transmission scheme provide impact on power overhead
Scheduling	Case 1: Full buffer data only, PF scheduling in time and frequency domain Case 2: VoIP only, capacity must be estimated Assumptions on feedback overhead should be described MCS table and details on link-to-system interface including link-level curves should be presented. Channel feedback delay should be modelled Delay impact should be included for VoIP results.
Link adaptation	Time-domain adaptation only Fixed power allocation
PHY Abstraction for Link to System Mapping	Mutual Information
H-ARQ	Asynchronous, non-adaptive HARQ overhead (associated control) should be accounted for in the system simulations
Power Control	Fixed power for data Power control for control signalling - not needed to be considered explicitly in system simulations
Interference Model	TBD
Frequency Reuse	1
Control signalling	Overhead must be described and accounted for assuming at least 95% area coverage reliability.

Table 3-1: Baseline system-level simulation assumptions for the downlink

Topic	Baseline for simulation, modelling assumptions
Basic transmission scheme	Parameters in table (include reference)
Basic modulation	QPSK, 16QAM, 64 QAM
Duplexing scheme	TDD and FDD
Resource block definition	TBD
Data multiplexing	Data transmissions: Control transmissions: Control (CQI, ACK/NACK etc) sent in separate resource blocks
Pilot structure	TBD
Receiver Structure	MMSE
Data channel coding	Convolutional turbo coding (CTC)
Multiple antenna configuration	Antenna configuration: 1x2 (reference) If MIMO is included in uplink then collaborative MIMO is the preferred scheme Impact on downlink signalling overhead should be described Channel estimation - should be modelled or at least calculations showing the impact presented
Random Access	Random access should be separately evaluated. Estimated overhead must be included in final performance estimates.
Scheduling	Case 1: Full buffer data only, PF scheduling in time and frequency domain Case 2: VoIP only, capacity must be estimated Assumptions on feedback overhead should be described MCS table and details on link-to-system interface including link-level curves should be presented
Link adaptation	Base-station (scheduler) controls resources, adaptive modulation and coding Slow closed loop power control included, updated at most every 10ms
H-ARQ	Asynchronous, non-adaptive HARQ overhead (associated control) should be accounted for in the system simulations
Power Control	See link adaptation
Interference Model	TBD
Frequency Reuse	1
Control signalling	Overhead must be described and accounted for assuming at least 95% area coverage reliability.

Table 3-2: Baseline system-level simulation assumptions for the uplink

The evaluation of different MU-MIMO schemes, which includes comparison with simple SU-MIMO w/o scheduling and SU-MIMO with scheduling, should take the following practical factors into consideration:

- The supported system throughput and user fairness
- The feedback overhead with the practical link budget constraints
- Comparison criteria for different MIMO schemes
  - Throughput with identical user antenna configurations
  - PER with identical user antenna configurations
  - Performance degradation vs. feedback overhead reduction
- Application scenarios for the different MIMO scheme, for example, SNR range, access PER for the users, etc.
- Different antenna configurations for different MIMO schemes, for example, 1x2, 2x1, 2x2, 4x2 and 4x4, etc.
- Practical MIMO pilot/preamble structure to support different MIMO schemes.
- Bandlimited white interference and noise
- Inter-cell interference modeling for different MIMO scheme
- Flat or larger delay spread fading channel – 3km/h, 30 km/h, 120km/h
- CQI feedback delay and frequency
- CQI generation – capacity formula based effective SINR method or others
- H-ARQ scheme with different MIMO scheme including H-ARQ parameter, for example, number of parallel H-ARQ processes, maximum number of retransmissions, adaptive H-ARQ transmission, etc
- Detection algorithms – linear MMSE, MMSE-SIC, and sub-MLD, etc.
- Transmit Antenna/Beam Selection.

4 Network Topology

The nineteen-cell network topology with wrap-around shall be used as the baseline network topology for all system-level simulations.

Nineteen-Cell Network Topology

The system is modeled as a network of 19 hexagonal cells with six cells surrounding the center cell in the first tier and 12 cells surrounding the center cell in the second tier.

Each cell has 3 sectors. Frequency reuse is modeled by planning frequency allocations in different sectors in the network. The configuration parameters are described in .

Parameter	Value
Number of cells	19
Number of sectors per cell	3
BS-BS distance	1.5 km
Frequency reuse patterns	1,3

Table 4-3: Topology parameters

Wrap Around Network Topology

Wrap around shall be applied to eliminate the network edge effect and to generate accurate simulation results. The cyclic wrap around structure is typically implemented using a toroidal surface by replicating 8 sets of 19 cells surrounding the basic 19 cell hexagonal network. Antenna orientations are defined to be consistent across the cyclic wrap around topology.

Deployment Scenario

The following channel environments shall be considered for IEEE 802.16m system-level simulations:

1. **Suburban macro-cellular:** This scenario is characterized by large cell radius (approximately 1-6 km BS to BS distance), high BS antenna positions (above rooftop heights, between 10-80 m, typically 32 m), moderate to high delay spreads and low angle spreads and high range of mobility (0 – 350 km/h).

2. **Urban macro-cellular:** This scenario is characterized by large cell radius (approximately 1-6 km BS to BS distance), high BS antenna positions (above rooftop heights, between 10-80 m, typically 32 m), moderate to high delay and angle spread and high range of mobility (0 – 350 km/h).

3. **Urban micro-cellular:** This scenario is characterized by small cell radius (approximately 0.3 – 0.5 km BS to BS distance) BS antenna positions at rooftop heights or lower (typically 12.5m), high angle spread and moderate delay spread, and medium range of mobility (0 – 120 km/h). This model is sensitive to antenna height and scattering environment (such as street layout, LOS)

The following table describes SISO channel environment parameters for system-level simulations:

Channel Scenario	Suburban Macrocell	Urban Macrocell	Urban Microcell
Lognormal shadowing standard deviation	8.9 dB	8.9 dB	NLOS: 8.9 dB LOS: 4 dB
Path loss model (dB), *d* is in meters	$31.5 + 35 \log_{10}(d)$	$28.6 + 35\log_{10}(d)$	NLOS: $34.53+38 \log_{10}(d)$

			LOS: 30.18 + 26*$\log_{10}(d)$

Table 4-4: SISO channel environment parameters for system-level simulations

The following table describes MIMO channel environment parameters for system-level simulations:

Channel Attribute	Suburban Macro-cellular	Urban Macro-cellular	Urban Micro-cellular
Number of paths (N)	6	6	6
Number of sub-paths (M) per-path	20	20	20
Mean AS at BS	E[$_{AS}$] =5^0	E[$_{AS}$] =15^0	NLOS: E[$_{AS}$] =19^0
AS at BS as a lognormal RV $s_{AS} = 10\,\hat{}\left(e_{AS}x + m_{AS}\right),\ x \sim h(0,1)$	$_{AS}$ = 0.69 $_{AS}$ = 0.13	8^0 $_{AS}$ = 0.810 $_{AS}$ = 0.34 15^0 $_{AS}$ = 1.18 $_{AS}$ = 0.210	N/A
r_{AS} $_{AoD}$ / $_{AS}$	1.2	1.3	N/A
Per-path AS at BS (Fixed)	2^0	2^0	5^0 (LOS and NLOS)
BS per-path AoD Distribution standard distribution	$(0,\ ^2_{AoD})$ where $_{AoD}$ r_{AS} $_{AS}$	$(0,\ ^2_{AoD})$ where $_{AoD}$ r_{AS} $_{AS}$	U(-40°, 40°)
Mean AS at MS	E[$_{AS,\,MS}$] = 68^0	E[$_{AS,\,MS}$] = 68^0	E[$_{AS,\,MS}$] =68^0
Per-path AS at MS (fixed)	35^0	35^0	35^0
MS Per-path AoA Distribution	$(0,\ ^2_{AoA}(\mathrm{Pr}))$	$(0,\ ^2_{AoA}(\mathrm{Pr}))$	$(0,\ ^2_{AoA}(\mathrm{Pr}))$
Delay spread as a lognormal RV $s_{DS} = 10\,\hat{}\left(e_{DS}x + m_{DS}\right),\ x \sim h(0,1)$	$_{DS}$ = - 6.80 $_{DS}$ = 0.288	$_{DS}$ = -6.18 $_{DS}$ = 0.18	N/A
Mean total RMS Delay Spread	E[$_{DS}$] = 0.17 s	E[$_{DS}$] = 0.65 s	E[$_{DS}$] = 0.251 s
r_{DS} $_{delays}$ / $_{DS}$	1.4	1.7	N/A
Distribution for path delays			U(0, 1.2 s)
Lognormal shadowing standard deviation	8.9 dB	8.9 dB	NLOS: 8.9 dB LOS: 4dB
Path loss model (dB), d is in meters	31.5 + 35$\log_{10}(d)$	28.6 + 35$\log_{10}(d)$	NLOS:34.53+38$\log_{10}(d)$ LOS:30.18 + 26*$\log_{10}(d)$

Table 4-5: MIMO channel environment parameters for system-level simulations

Modified COST231 Hata Urban Path Loss Model

The modified COST231 Hata model is typically used by various standardization organizations [ref] to compute the path loss in urban/suburban environments for RF frequencies around 2 GHz. According to this model, the path loss is given by

$$PL_{\mathrm{modHata}}(d) \quad 45.5 \quad 0.7H_{MS} \quad 13.82\log_{10}(H_{BS}) \quad (44.9 \quad 6.55\log_{10}(H_{BS}))\log_{10}(d/1000) \\ (35.46 \quad 1.1H_{MS})\log_{10}(f) \quad C \qquad (4.3\text{-}2)$$

where H_{BS} and H_{MS} are the BS and MS heights in m, d is distance between the BS and the MS in meters, f is carrier frequency in MHz, and C is a constant factor set to $C \quad 0$ dB for suburban scenarios and $C \quad 3$ dB for urban scenarios. In the system level simulator, the modified COST231 Hata model is used according to Equation (4.3-2) with C chosen to be equal to 3 dB. This model is referred to as the urban path loss model.

Lognormal Shadowing

The attenuation between a mobile and the transmit antenna of the i-th cell site, or between a mobile and each of the receiving antennas of the i-th cell site is modeled by

$$L_i \quad k_o D_i \quad 10^{X_i/10} R_i^2 \qquad (4.3\text{-}3)$$

where D_i is the distance between the mobile and the cell site, is the path loss exponent and X_i represents the shadow fading which is modeled as a Gaussian distributed random variable with zero mean and standard deviation . X_i may be expressed as the weighted sum of a component Z common to all cell sites and a component Z_i that is independent from one cell site to the next. Both components are assumed to be Gaussian distributed random variables with zero mean and standard deviation independent from each other, so that

$$X_i \quad aZ \quad bZ_i \qquad \text{such that} \qquad a^2 \quad b^2 \quad 1 \qquad (4.3\text{-}4)$$

Typical parameters are 8.9 and $a^2 \quad b^2 \quad \frac{1}{2}$ for 50% correlation. The correlation is 0.5 between sectors from different cells, and 1.0 between sectors of the same cell.

Equipment and Network Configuration Parameters

The BS and MS equipment models are characterized by their transmit power, height, number of antennas, and antenna pattern. It is assumed that all BS and MS equipment are configured identically across the network. In the following table, the bolded values are those used for the evaluation of the IEEE 802.16e reference system.

Network Configuration Parameters

Parameter	Description	Value Range

N_c	Number of cells.	**19**
S	Number of sectors/cell.	1, **3**, 4, 6
$N_s \quad SN_c$	Total number of sectors.	19, **57**, 76, 114
$r_{BS \ BS}$	BS-to-BS distance	0.5 to 30 km **(1.5 km)**
$r_{MS \ BS}$	Minimum Mobile-to-BS distance	**35m**
N_{Sub}	Number of active subscribers/sector	TBD
$_{BS}$	Orientation (boresight angle) of each sector as defined by 3GPP-3GPP2 [10]	$S \quad 3: \ _{BS} \quad 30,150,270$ $S \quad 6: \ _{BS} \quad 0,60,120,...300$
K	Number of frequency allocations in the network.	**1**, 2, 3, 4, 6
F_{BS}	Frequency allocation (integer index) used in each BS sector.	**1**, 2, 3, 4, 5, 6
	Operating Frequency	2.0–3.5 GHz (**2.5 GHz**)
	Duplexing Scheme	**TDD** and FDD

Table 4-6: Network Configuration Parameters

Base Station Model

Parameter	Description	Value Range
$P1_{BS}$	BS power amplifier 1dB compression point	39-60 dBm
PAR_{BS}	Peak-to-average backoff at BS	9-11 dB
P_{BS}	MAX transmit power per sector/carrier	30-51 dBm 43 dBm @ 5MHz bandwidth **46 dBm @ 10MHz bandwidth** 49 dBm @ 20MHz bandwidth and similarly scalable for other bandwidths
H_{BS}	Base station height	10-50m (**32 m**)

G_{BS}	Gain (boresight)	**17 dBi**
$_{BS}$	3-dB beamwidth as defined by 3GPP-3GPP2 [10]	$S\ \ 3:\ \ _{BS}\ \ 70^{0}$ $S\ \ 6:\ \ _{BS}\ \ 35^{0}$
G_{FB}	Front-to-back power ratio	**20 dB**
M_{TX}	Number of transmit antennas	1,**2**,3,4
M_{RX}	Number of receive antennas	1,**2**,3,4
d_{BS}	BS antenna spacing (ref: ULA)	$/\ 2,\ 4\ \ ,10$
$_{MS}$	MS Antenna correlation	0.5
NF_{BS}	Noise figure (transmit & receive)	4-6 dB (**5 dB**)
HW_{BS}	Hardware loss (cable, implementation, etc.)	**2 dB**

Table 4-7: BS equipment model

Mobile Station Model

Parameter	Description	Value Range
$P1_{SS}$	MS power amplifier 1dB compression point	29-54 dBm
PAR_{SS}	Peak-to-average backoff at SS	9-11 dB
P_{SS}	RMS transmit power/per SS	20-45 dBm (**23 dBm**)
H_{SS}	Subscriber station height	1.5-7 m (**1.5 m**)
G_{SS}	Gain (boresight)	**0 dBi**
$\{\ _{SS}\},\ G(\{\ _{SS}\})$	Table of Gains as a function of Angle-of-arrival	Omni
N_{TX}	Number of transmit antennas	**1**,2
N_{RX}	Number of receive antennas	1,**2**,3,4

d_{SS}	SS antenna correlation	0-0.7 (**0.5**)
	SS antenna gain mismatch	0-5 dB (**3 dB**)
NF_{SS}	Noise figure (transmit & receive)	6-7 dB (**7 dB**)
HW_{SS}	Hardware loss (cable, implementation, etc.)	**2 dB**

Table 4-8: MS Equipment Model

Parameter	Description	Value Range
OFDMA symbol parameters		
BW	Total bandwidth	5, **10**, 20 MHz
N_{FFT}	Number of points in full FFT	512, **1024**, 2048
f	Subcarrier spacing	10.9375 kHz
T_S 1 / f	OFDMA symbol duration	91.43 us
CP	Cyclic prefix length (fraction of T_S)	1/2, 1/4, **1/8**, 1/16
T_O	OFDMA symbol duration w/ CP	102.86 us for CP=1/8
Frame parameters		
T_F	Frame length	2, **5**, 10, 20 ms
N_F	Number of OFDMA symbol in frame	18,**47**,95,193
$R_{DL\ \ UL}$	Ratio of DL to UL (TDD mode)	1:1, **2:1**
T_{duplex}	Duplex time between UL and DL	0.67 to 20 ms
T_{class}	Classification of traffic	Control or Data
Permutation parameters		
DL_{Perm}	DL permutation type	**PUSC**, AMC, FUSC
UL_{Perm}	UL permutation type	**PUSC**, AMC,

BS_{Nused}	DL: number of sub-carriers for BS TX	For 10MHz, PUSC: FUSC: AMC:
SS_{Nused}	UL: number of sub-carriers for SS TX	PUSC/FUSC: SS_{Nused} 24 AMC: SS_{Nused} 18
F_{sim}	Data sub-carriers explicitly simulated	
$SubCh_{MAX,DL}$	Maximum number of subchannels in DL permutation	AMC (48), **PUSC (30)**, FUSC (16)
$SubCh_{MAX,UL}$	Maximum number of subchannels in UL permutation	AMC (48), **PUSC (35)**

Table 4-9: OFDMA Air Interface Parameters

Parameter	Description	Value Range
f	Carrier frequency	1.9-2.5 GHz **(2.5 GHz)**
PL	Path loss model	**COST-HATA-231,** Erceg
$_{SF}$	Log normal shadowing standard deviation	8-12dB (**8.9dB**)
$_{SF}$	Shadowing correlation	$_{SF}$ 0.5
L_P	Penetration and other losses	10-20dB **(10 dB)**
	Thermal noise density	**-174 dBm/Hz**

Table 4-10: Methodology Parameters

Description	Value Range
Link adaptation	**Dynamic with delay feedback**
Channel estimation	**Realistic/ideal**
MIMO Support DL	**Alamouti STC, VSM**
MIMO Support UL	**Collaborative SM**

MIMO Switch	**Adaptive STC/ VSM Switch**
Coding	**CTC**
Control/MAP overhead modeling	**Dynamic**
Control/MAP channel reliability	**Realistic**
Hybrid ARQ	**Chase Combining with up to 4 retransmissions**
MAC ARQ	**Enabled for BE traffic**
Power Control	**UL**
Traffic models	Full buffer, **Realistic traffic mix**
Scheduling algorithm	**Proportional fair**
ACK/CQI/BW-REQ Feedback channel error	**1%**
CQI Feedback delay	**2 frames**

Table 4-11: Dynamic System Simulation Features

5 Channel Models

Described in a separate contribution

6 OFDMA Numerology

The backward compatibility with the IEEE 802.16e reference system [ref] requires the use of the same OFDMA numerology for the IEEE 802.16m in the frequency range around 2.5 GHz. The details of the OFDMA numerology are summarized in . A radio frame size of 5 ms consistent with the IEEE 802.16e reference system shall be used.

Transmission Bandwidth BW (MHz)	5	10	20
Over-sampling Factor n	28/25	28/25	28/25
Sampling Frequency Fs (MHz)	5.6	11.2	22.4
Sample time ($1/F_s$, nsec)	178	89	44.6
FFT Size	512	1024	2048
Number of Guard Sub-Carriers	Permutation Scheme Dependent	Permutation Scheme Dependent	Permutation Scheme Dependent
Sub-Carrier Spacing Δf (kHz)	10.9375	10.9375	10.9375
Useful OFDM Symbol Duration	91.4	91.4	91.4

Tu = 1/Δf (us)			
Cyclic Prefix Tg	OFDM Symbol Duration Ts Ts=Tu+Tg (us)	Number of OFDM Symbols per Frame N	Idle Time (us) Frame _Size – N*Ts
Tg=1/8 Tu	91.4 + 11.42=102.82	48	64.64

Table 6-12: OFDMA numerology for IEEE 802.16m

To compare the performance IEEE 802.16m candidate proposals to the IEEE 802.16e reference system, the parameters consistent with the reference system shall be utilized. These parameters are identified in the above table. Link-level and system-level simulation results shall be conducted and reported based on 10 and 20 MHz channel bandwidth using a center frequency of 2.5 GHz.

7 PHY Abstraction

The objective of a PHY abstraction is to accurately predict link layer performance in a computationally simple way. The requirement for an abstraction stems from the fact that simulating the physical layer links between multiples BS's and MS's in a network/system simulator can be computationally prohibitive. The abstraction should be accurate, computationally simple, relatively independent of channel models, and extensible to interference models and multi-antenna processing.

Background

In the past, system level simulations characterized the average system performance, which was useful in providing guidelines for system layout, frequency planning etc. For such simulations, the average performance of a system was quantified by using the topology and macro channel characteristics to compute a geometric (or average) SINR distribution across the cell. Each subscriber's geometric SINR was then mapped to the highest modulation and coding scheme (MCS), which could be supported based on link level SNR tables that capture fast fading statistics. The link level SNR-PER look-up tables here served as the PHY abstraction for predicting average link layer performance. Examples of this static methodology may be found in -.

Current cellular system design is based on exploiting instantaneous channel conditions for performance enhancement. Channel dependent scheduling and adaptive coding and modulation are examples of channel-adaptive schemes employed to improve system performance. Therefore, current system level evaluation methodologies are based on explicitly modeling the dynamic system behavior by including fast fading models within the SLS. Here the SLS must support a PHY abstraction capability to accurately predict the instantaneous performance of the link layer.

Dynamic PHY Abstraction Methodology

PHY abstraction methodology for predicting instantaneous link performance for OFDM systems has received considerable attention in the standards literature -. The role of a PHY abstraction is to predict coded BER/PER given a received channel realization across the OFDM sub-carriers used to transmit the coded FEC block. To predict coded performance, the post-processing SINR values at the input to the FEC decoder are considered as input to the PHY abstraction mapping. Since, for OFDM, the coded block is transmitted over several sub-carriers, the post-processing SINR values of the pre-decoded streams are non-uniform. The PHY abstractions defined thus far, compress these vector of SINR values to a single effective SINR value, which can then be further mapped to a BLER/PER number.

Several PHY abstractions to predict the instantaneous link performance have been proposed in literature. Examples include effective SINR , mean instantaneous capacity (-), exponential-effective SINR (EESM, ,-), Mutual information effective SINR (MIESM, ,) etc. Each of these PHY abstractions uses a different function to map the vector of SINR values to a single number. Given the instantaneous effective SINR, mean capacity or mutual information, the PER (block error rate) for each MCS is calculated using a suitable mapping function for each MCS scheme.

The mutual information based PHY abstraction shall be used as the baseline PHY abstraction methodology for 802.16m system evaluation. In the following we specify the details associated with the mutual information PHY abstraction.

Mutual Information PHY Abstraction

Mutual information is a metric for mapping the vector of SINR values to an effective SINR metric . The mutual information per symbol is computed as a function of the M-ary modulation scheme, with m bits/symbol, as follows:

$$SI(SINR(i),m(i)) \quad E_{XY} \quad \log_2 \quad \frac{P(Y \mid X, SINR(i))}{\underset{X}{P(X)P(Y \mid X, SINR(i))}} \qquad (7.2\text{-}5)$$

In the above, Y is the received symbol and $P(Y \mid X, SINR)$ is the AWGN channel transition probability density conditioned on the input symbol X. It is assumed that P(X) = 1/M, where M is the size of the M-ary modulation alphabet.

Assuming *N* sub-carriers are used to transmit a coded block, the received mutual information over a coded block is computed as:

$$RBI(i) \quad \overset{N}{\underset{i\ 1}{}} SI(SINR(i),m(i)) \qquad (7.2\text{-}6)$$

We note that the even though we refer to the coded block being carried over a set of sub-carriers, in general, the code block may be carried over multiple dimensions, including the spatial dimensions available with MIMO. Also note that in the above, the mutual information may be computed even with non-uniform modulation across the coded block. Rather, than mapping the received mutual information to an effective SINR value (Mutual Information Effective SINR-MIESM), it is more useful to compute the normalized mutual information per bit, which only depends on the code rate and is independent of the modulation schemes used to transmit the coded block. The received bit information rate is expressed as follows:

$$RBIR(i) = \frac{\sum_{i=1}^{N} SI(SINR(i), m(i))}{\sum_{i=1}^{N} m(i)} \quad (7.2\text{-}7)$$

The advantage of computing the RBIR is that the relationship between the RBIR and the PER is dependent only on the AWGN curves for the code rate and is independent of the modulation scheme. This feature is a very useful in computing the PHY abstraction for cases where the coded block comprises of mixed modulation symbols. Further details on the mutual information PHY abstraction metric may be found in .

We further note that an adjustment parameter may be specified with the RBIR metric that can account for deviations of the RBIR mapping with respect to the AWGN curves. This adjustment parameter is illustrated by the following equation.

$$RBIR(i) = \frac{\sum_{i=1}^{N} SI(SINR(i) / SINR_{adjust}, m(i))}{\sum_{i=1}^{N} m(i)} \quad (7.2\text{-}8)$$

The exact specification of this adjustment parameter will be determined through simulations and shall be specified along with the PHY abstraction tables, once the 802.16m numerology is specified.

We note that the RBIR/MIESM metric has been extensively compared with capacity-based effective SINR, as well as with the EESM metric and its performance has been shown to be superior ,. Further, it is a very useful metric to model mixed modulation scenarios, for example those encountered when modeling adaptive HARQ or adaptive bit loading. The RBIR based mutual information based PHY abstraction can be used as the baseline IEEE 802.16m PHY abstraction methodology. In the following we specify the details associated with the mutual information PHY abstraction.

SINR Computation

All PHY abstraction metrics are computed as a function of post-processing SINR values across the coded block at the input to the decoder. The post-processing SINR is therefore dependent on the receiver algorithm used to demodulate the symbols. As an illustration of how the post-processing SINR values can be computed, we consider the simple case of a single-input-single output (SISO) system with a matched filter receiver. The received signal at the ith sub-carrier for m^{th} target user is calculated as:

$$Y^m(i) = P_d^m P_{loss}^m H^m(i) S(i) + \sum_{j=1}^{N_I} P_I^j P_{loss}^j G^j(i) X^j + N(0, \sigma^2) \qquad (7.3\text{-}9)$$

where

P_d^m is the total transmit power from BS (per sector) or m^{th} MS
P_{loss}^m is the path loss including shadowing and antenna gains
$H^m(i)$ is the channel gain for the desired MS for the i^{th} sub-carrier.
$P_I^j, P_{loss}^j, G^j(i)$ are the transmit power, path loss and the channel gain between the desired MS and the j^{th} interferer. S, X^j are the transmitted symbols of the desired MS and the j^{th} interferer, respectively. $N(0, \sigma^2)$ is the receiver AWGN noise with variance σ^2.
The post-processing SINR, assuming a matched filter receiver $H^m(i)^* Y^m(i)$, may be expressed as

$$SINR^m(i) = \frac{P_d^m P_{loss}^m \left|H^m(i)\right|^2}{\sigma_n^2 + \sum_{j=1}^{N_I} P_I^j P_{loss}^j \left|G^j(i)\right|^2} \qquad (7.3\text{-}10)$$

In the above we assume that ideal knowledge of interference statistics per sub-carrier is available for post-processing SINR computation. For MIMO systems, post-processing SINR may be similarly calculated, especially if linear receivers are used for MIMO processing. We assume that linear minimum mean square (LMMSE) receivers will be used as a baseline receiver for SLS methodology. Advanced receivers, such as the maximum likelihood receiver, and the associated PHY abstractions may be considered on an as needed basis and are for further study (FFS). The following section describes the post-processing SINR calculations for MIMO reception assuming the baseline LMMSE receiver.

Post Processing SINR Calculation for MIMO

To illustrate the post processing SINR calculation for a MIMO system based on an LMMSE receiver, we assume an *M* transmit and *L* receive antenna system for Downlink transmission. Since these calculations are illustrative, for the sake of simplicity, we assume that *M* spatial streams are transmitted and $L \geq M$. We also assume that interferers and the desired signal use the same MIMO scheme for transmission. The simplified signal model is described as follows:

$$\underline{Y}^m(i) = \underline{H}^m(i)\underline{S}(i) + \sum_{j=1}^{N_I} G^j(i)\underline{X}^j(i) + \underline{N}(0, \sigma^2 \underline{I}) \qquad (7.3\text{-}11)$$

where

$\underline{Y}^m(i)$ is the *L* dimensional received signal at the MS for the i^{th} sub-carrier.
$\underline{H}^m(i)$ is the *L X M* channel gain matrix between the desired BS and the MS for the i^{th} sub-carrier.
$\underline{G}^m(i)$ is the *L X M* channel gain matrix between the interfering BS and the MS for the i^{th} sub-carrier.
$\underline{S}(i), \underline{X}^j(i)$ are the *M* dimensional transmit symbol vectors of the desired MS and the j^{th} interferer, with covariance $\sigma_d^2 \underline{I}$ *and* $\sigma_{I,j}^2 \underline{I}$, respectively. $\underline{N}(0, \sigma^2 \underline{I})$ are the receiver AWGN noise vector with covariance $\sigma^2 \underline{I}$. $\underline{I}$ is the *M x M* identity matrix.

At the MS, a LMMSE receiver is used to demodulate the transmitted signal vector, and

$$\hat{\underline{S}}(i) = W(i)\underline{Y}^m(i).$$

Here the non-interference-aware MMSE weights *W* are specified as

$$W(i) = \left(\underline{H}^{m*}\underline{H}^m + \frac{\sigma^2}{\sigma_d^2} I\right)^{-1} \underline{H}^{m*} \qquad \mathbf{(7.3\text{-}12)}$$

where, the expression , (.)* is the Hermitian operator.

The post-processing SINR can be computed by defining the following expressions:

$$E(i) = W(i)\underline{H}^m(i),$$
$$D(i) = diag(E(i)),$$

denotes the desired signal component. $I_{self}(i) = E(i) - D(i)$, is the self interference between MIMO streams.

The post-processing SINR for i^{th} sub-carrier and the k^{th} MIMO stream is given as:

$$SINR^k(i) \quad \frac{diag \quad {}^2_d D(i) D(i)^* \;{}_{kk}}{diag \quad {}^2 W(i) W(i)^* \quad {}^2_d I_{self} I_{self}^* \quad \sum_{j\ 1}^{N_I} \quad {}^2_{I,j} W(i) G^j(i) G^j(i)^* W(i)^* \;{}_{kk}} \qquad \textbf{(7.3-13)}$$

Here, ideal knowledge of the interfering statistics is assumed for the computation of the post-processing SINR, even though the MMSE receiver does not assume knowledge of the interference statistics.

Interference Aware PHY Abstraction

As noted earlier, accurate modeling of post-processing SINR in the presence of interference requires perfect knowledge of per-sub carrier interference statistics. The baseline methodology shall assume that perfect knowledge of interference statistics per sub-carrier is available at the receiver. We realize that this is an ideal assumption not likely to be met with practical receivers, and a suitable interference-aware PHY abstraction will become necessary with the use of practical receivers operating in the presence of interference. The specification of a standard practical interference-aware receiver is for further study (FFS).

Practical Receiver Impairments

The evaluation should account for practical receiver implementation losses resulting from channel estimation errors, synchronization errors etc. Inclusion of channel estimation losses and other receiver impairments is FFS; however the minimum level required is of adding a fixed implementation loss backed by analysis/simulation. The channel estimation algorithm that should be assumed as baseline is a linear channel estimation from known symbols (linear means each channel estimate is a linear function of the received pilots), with reasonable delay considering the link latency requirements.

Effect of Different Block Sizes

The PHY abstraction predicts the link performance, in terms of PER, for a coded FEC block. Often it is required to predict the PER of a burst of data comprising several code blocks. Here we need to extrapolate the overall PER of the burst as a function of the predicted PER across the code blocks. We note that if the channel is varying slowly, packet errors across code blocks will be correlated for the blocks that are contiguously allocated along time. However, due to sub-carrier permutation, packet errors across code blocks allocated along the frequency axis will appear independent. The overall PER of the code blocks that are correlated may be computed as the maximum of the individual PER. Whereas, the PER for code blocks that are independent, may be computed via the independence assumption. Therefore the overall predicted PER across the burst shall be modeled as

$$P_{burst} \quad 1 \quad \underset{i \ \ Independendnet \ Blocks}{} \quad (1 \quad \underbrace{\max}_{j \ \ correlated \ blcoks} \quad PER_{i,j}) \tag{7.6-14}$$

The exact procedure for determining the number of correlated blocks in a burst is dependent on the Doppler and delay spread of the channel, and the exact specification is FFS

PHY Abstraction for H-ARQ

PHY abstraction of H-ARQ depends on the H-ARQ method and should be justified by link level simulations showing the PER forecast versus actual PER in each retransmission.

The following abstraction is proposed as baseline:

For Chase combining (CC): the SINR values of the sub-carriers are summed across retransmissions, and these combined SINR values will be fed into the PHY abstraction.

For Incremental redundancy (IR): the transmission and retransmissions are regarded as a single codeword, and all the SINR values are fed into the PHY abstraction, which is calibrated according to link level PER curves of the entire transmission (including the retransmission). For MI/EESM/MIC abstraction, there is no need to store the SINR values, only the sum metric over the previous transmissions, so this method is simpler than the first.

For methods combining CC and IR the second approach is preferred but should be justified by link level simulations.

Summary of Baseline PHY Abstraction Assumptions

PHY Abstraction Modeling Features	Baseline Assumptions
PHY Abstraction metric	Mutual Information (MI)
Receiver Modeling	Linear Minimum Mean Square (LMMSE)
Interference Modeling at the Receiver	Ideal knowledge of per sub-carrier interference statistics
Receiver Impairments	Practical Receiver Linear channel estimation Specific abstraction is FFS
HARQ Modeling	CC: Assume perfect combining of SINR across re-transmissions IR: Combine MI metrics across re-transmissions
Advanced Receivers	FFS
Practical Receiver Impairments	FFS
Practical Interference Aware Receivers	FFS

Table 7-13: Baseline PHY abstraction Assumptions

8 Link Adaptation

System level simulations shall include adaptation of the modulation and coding schemes, according to link conditions. The system performance shall be tested, considering link adaptation algorithm application.

Adaptive Modulation and Coding

The evaluation methodology assumes adaptive modulation and coding with various modulation schemes and channel coding rates is applied to packet data transmissions. In the case of MIMO, different modulation schemes and coding rates may be applied to different streams. The algorithm for power, MIMO rank, and modulation adaptation per resource block is FFS.

Chanel Quality Feedback Delay

Channel quality feedback processing delay accounts for the latency associated with the measurement of channel at the receiver, the decoding of the feedback channel, and the lead-time between the scheduling decision and actual transmission. The delay in reception of the channel quality feedback delay must be modeled to accurately predict system performance.

Link Adaptation with H-ARQ

The link adaptation algorithm should be optimized to maximize the performance at the end of the H-ARQ process (e.g. maximize the average throughput under constraint on the delay and PER, or maximize number of users per service).

Adaptive H-ARQ in which the parameters of the retransmission are changed according to channel conditions reported by the MS may be considered. Currently the evaluation methodology assumes H-ARQ retransmissions do not depend on CQI, and modeling of adaptive H-ARQ is FFS.

Channel Quality Feedback

Channel quality measurements sent by the MS are proposal specific and may be different from the metrics used in the PHY abstraction (for example physical average SNR can be used as metric), as they are affected by practical estimation and implementation considerations.

The scheduling will be done based on the reported metric rather than ideal abstraction.

The estimation errors of the CQI metric (or other reports) should be taken into account. A proposed way is to measure the estimation errors in link level simulation and feed them artificially into the SLS by adding noise to the true CQI value.

Scheduler MCS Selection

The scheduler should take into account the following factors when selecting the user and the MCS:

1. A CQI metric which doesn't directly map to packet error rate forecast (e.g. SNR metric rather than MI/EESM)
2. CQI metric estimation errors
3. The user mobility and the delay between the measurement and the allocation (which inserts errors in the throughput forecast)
4. H-ARQ

These factors result in uncertainty regarding the throughput and packet error rate of a considered transmission. The implementation of the scheduler is system specific.

For the baseline proportional fair scheduler, the throughput and packet error rate (per user, resource block and modulation scheme) used by the scheduler when deciding on allocation and modulation, will be replaced by the *estimated* mean throughput and *estimated* mean packet error rate given the reported CQI (i.e. $Thro\hat{u}ghput \quad E\ Throughput \mid CQI$, $P\hat{E}R \quad E\ PER \mid CQI$.)

The simulation may assume per-user adaptation by an outer loop based on ACK/NACK, but this loop doesn't need to be simulated. For example, the mean PER and throughput estimations may rely on knowledge of slowly changing parameters such as velocity and geometry which are not reported, the underlying assuming being that such adaptation can be made by an outer loop.

9 Calculation of Overhead

Calculation of L1 overhead

The L1 overhead shall be accounted for the purpose of calculation of system performance metrics such as spectral efficiency, user throughput, etc. The following are the list of L1 overhead that shall be accounted for in the overhead calculation:

1. Number of sub-carriers that carry preamble ($N_{preamble}$)
2. Number of sub-carriers that are used as the guard carriers and DC sub-carrier (N_{guard}).
3. Number of sub-carriers that are assigned to the TX/RX switching points (N_{gap}) (for TDD duplex scheme only).
4. Number of sub-carriers that are used to carry pilots (N_{pilot}) in downlink or uplink sub-frame.
5. The cyclic prefix (CP) or the guard interval (GI) is accounted for through the actual number of OFDM symbols within a frame.

Given transmission bandwidth (BW) and sub-carrier spacing (1/T when there is no cyclic prefix), the ideal number of sub-carriers per OFDM symbol becomes $BW \quad T$. The number of OFDM symbols over frame duration (T_f) excluding L1 overhead can be expressed as $\frac{T_f}{T}$. Hence, the total number of available sub-carriers over BW and T_f becomes $M \quad BW \quad T_f$.

However, due to L1 overhead, the actual number of available sub-carriers (N) over a frame and the transmission bandwidth will be smaller than M.

$$L1_{overhead} \quad \frac{M \quad N}{M} \quad 100 \text{ in \%}$$

(9.1-15)

As an example in IEEE 802.16e reference system, M=10 MHz * 5 ms = 50000. Using DL PUSC, 47 OFDM symbols are available (including the preamble and cyclic prefix overhead). The number of usable sub-carriers for both data and pilot is 840*47 including the effect of guard sub-carriers. In PUSC, the number of pilots is 840*47/56*8=5640. Thus, N is equal to 840*47*48/56=33840. Hence, the L1 overhead becomes 32.3%.

Calculation of L1+L2 overhead

The L2 overhead includes the following:

1. The number of OFDM symbols (or sub-carriers) that are used for MAP,
2. The average number of ODFM symbols (or sub-carriers) that are used for system configuration information (FCH, DCD/UCD).
3. The number of OFDM symbols (or sub-carriers) that are used for ACK/NACK,
4. The number of OFDM symbols (or sub-carriers) that are used for CQICH,
5. The number of OFDM symbols (or sub-carriers) that are used for Ranging

Let L denote the number of sub-carriers over a frame and the bandwidth excluding L2 overhead such as MAP, control channel, etc. Then, the L1+L2 overhead is defined

$$L1 \quad L2_{overhead} \quad \frac{M \quad L}{M} \quad 100 \text{ in \%.}$$

The L2 overhead can be written as

$$L2_{overhead} \quad \frac{N \quad L}{N} \quad 100 \text{ in \%.}$$

Note that $L1 \quad L2_{overhead} \quad L1_{overhead} \quad L2_{overhead}$.

10 Calculation of PAPR (Informative)

PAPR is used to calculate the TX power amplifier back-off value. Since it is not desirable to change the back-off value at every symbol, the rms transmit power should be evaluated over long period of time. For the calculation of average power, the worst case assumption, which causes maximum average power, should be made; e.g., maximum loading of data. In addition it is desirable for the P_{av1} defined below to have similar value from symbol-to-symbol.

P_{av1} denotes the average power over one OFDM symbol duration defined by

$$P_{av1} \quad \frac{1}{T}\int_0^T |s(t)|^2 dt$$
(9.2-16)

where s(t) is the time domain OFDM signal. Note that s(t) may include a weight matrix to take into account the transmit beamforming, and closed-loop MIMO if any. Note that the weight matrix is a function of channel and can increase the peak power.

P_{av} is an ensemble average of OFDM symbols over all possible random data, and channel

$$P_{av} \quad E\,|s(t)|^2$$ **9.2-17**)

In transmit antenna selection, the average power should be evaluated only when the antenna is selected in order to get the maximum (or worst case) average power.

P_{max} is the peak power measured over one OFDM symbol duration and it is defined as

$$P_{\max} \quad \max_{0\ t\ T}|s(t)|^2$$
(9.2-18)

Then, the PAPR1 and PAPR are defined as follows

$$PAPR_1 \quad \frac{P_{\max}}{P_{av1}}$$
$$PAPR \quad \frac{P_{\max}}{P_{av}},$$
(9.2-19)

The CCDF of PAPR1 and PAPR should be evaluated over all possible channel conditions, and random OFDM signals. In the PAPR simulations, the signal shall be over-sampled at least 8 times. The guard interval can be included in the OFDM symbol duration (T). From P_{av} and CCDF of PAPR, the back-off value and operating point of PA can be obtained.

Instantaneous PAPR

The instantaneous power can be written as

$$P_i \quad |s(t)|^2.$$

We can define two different instantaneous PAPR by normalizing using either P_{av1} or P_{av}

$$PAPR_{i1} \quad \frac{P_i}{P_{av1}}, \text{ and}$$

$$PAPR_i \quad \frac{P_i}{P_{av}}.$$

Note that we should look at lower probability in CCDF of $PAPR_i$ than that in PAPR case depending on the number of samples during one OFDM symbol.

11 H-ARQ

The stop-and-wait Hybrid ARQ (HARQ) protocol is implemented with multiple HARQ streams in each frame for every served MS. The scheduler explicitly considers the status of the HARQ streams when computing the scheduling metric and deciding priority for scheduling streams. When HARQ is enabled, retransmissions are modeled based on the H-ARQ option chosen. HARQ can be configured as synchronous/asynchronous with adaptive/non-adaptive modulation and coding schemes for Chase combining or incremental redundancy operation. The HARQ model and type shall be specified with chosen parameters, such as maximum number of retransmissions and etc.

In the case of H-ARQ IR the new estimated PER would be derived according to the new code rate after the additional bit add which decrease the code rate from rate R1 to rate R2.
The MAC scheduler must efficiently allocate the available radio resources on frame-boundaries to satisfy the QoS requirements of competing flows by exploiting time-varying channel conditions under fairness criteria, if any.

12 Scheduler

DL scheduler

A DL scheduler at the BS partitions the two dimensional DL frequency subchannel-OFDMA symbol resources between active DL flows. In its most generic form, a MAC scheduler may calculate a metric per flow at time t $M_i(t)$ that is a function of many attributes specific to the flow, and serve the flows in descending order of the metric values, where $M_i(t) \quad f(QoS_i(t), CQI_i(t), Delay_i(t), Throughput_i(t)...)$ [33]. There are several options for constructing the metric function, and each may serve a useful purpose depending on the design objectives.

For the baseline simulation, a generic proportional fair scheduler with scheduling metric specified in Section shall be used, for full-buffer traffic model. In the general deployment case, the MAC scheduler should be capable of handling traffic mix on different QoS service classes that are enabled by the air interface. The proponent may present additional results with a more sophisticated scheduler other than proportional fair scheduler and shall specify the scheduler algorithm in detail.

UL scheduler

A UL scheduler at the BS partitions the two dimensional UL frequency subchannel-OFDMA symbol resources between active UL flows. UL scheduler is very similar to Downlink Scheduler. UL scheduler maintains the request-grant status of various uplink service flows. Bandwidth requests arriving from various uplink service flows at the BS will be granted in a similar fashion as the downlink traffic.

Scheduling Metric for Proportional Fair Scheduler

At any scheduling instant t, the scheduling metric $M_i(t)$ for subscriber i used by the proportional fair scheduler is given by

$$M_i(t) \quad \frac{T\_inst_i(t)}{T\_smoothed_i(t)} \tag{12.3-20}$$

where $T\_inst_i(t)$ is the data rate that can be supported at scheduling instant t for subscriber i $T\_inst_i(t)$ is a function of the instantaneous SINR, and consequently of the modulation and coding scheme that can meet the PER requirement. $T\_smoothed_i(t)$ is the exponentially smoothed throughput at the scheduling instant t for user i. For the scheduled subscriber, $T\_smoothed_i(t)$ is computed as

$$T\_smoothed_i(t) = \frac{1}{T_{PF}} * T\_inst_i(t-1) + (1 - \frac{1}{T_{PF}}) * T\_smoothed_i(t-1) \tag{9.2}$$

and for unscheduled subscriber,

$$T\_smoothed_i(t) = (1 - \frac{1}{T_{PF}}) * T\_smoothed_i(t-1) \tag{9.3}$$

where T_{PF} 1 represents the latency time scale of the PF scheduler.

The trade-off between spectral efficiency and fairness is implicit in the choice of the latency time scale. Larger values of T_{PF} make it possible for the scheduler to wait longer to schedule subscribers when channel conditions are most favorable, thereby achieving higher spectral efficiency. Shorter time scales reduce the amount of flexibility the scheduler has in scheduling a particular subscriber since throughput becomes the dominant factor in the value of the metric.

Although the throughput for an unscheduled subscriber drops with every scheduling opportunity that is missed, the metric for the same subscriber increases, ultimately forcing the subscriber to be scheduled within the latency time scale of operation.

13 Interference Modeling

One of the key benefits of the WiMAX air interface is the capability to enable frequency reuse of 1. This allows the same frequency channel to be shared by all cells in a network, and thereby ease deployment by eliminating frequency planning. This attribute is already available in CDMA networks, and is highly desirable in OFDMA networks. Universal frequency reuse pattern, however, causes the system to become interference limited. The nature of interference seen by a MS in downlink and a BS in uplink is typically time-frequency selective. The network simulator models interference using a realistic channel model, which includes both slow fading and fast time-frequency selective fading components. The simulator ascribes the same fast fading channel model to a MS in the downlink & uplink, example ITU Ped A.

For simplicity, in early simulations it is assumed that interference has same fast fading channel model as desired signal, and in later detailed simulations the SCM channel model is used. Also, as an optional simplification, the time-frequency channel of only the strongest B interferers may be modeled to reduce simulation complexity. A typical value for B may be 14. The remaining interferers are then modeled as (spatially) white and non-frequency selective AWGN processes whose variances are changing in time based on a Raleigh fading process.

Another important consideration in modeling interference is how the base stations in the network allocate resources. This is especially important if the network is not fully loaded, since OFDMA resource allocation may be optimized in these networks to reduce interference. If center cell method is used, it is expected that 2 tiers of interferers are modeled in downlink, and 4 tiers in uplink to yield accurate interference statistics. In addition, the BS schedulers in interfering cells need to be abstracted such that resources are allocated on a time-frequency grid according to scheduling algorithm. The minimum unit of allocation is a slot, comprising of 1 or more frequency sub-channels times 1 or more symbol durations, depending on the permutation scheme. The number of slots allocated is a fraction of total slots available in a frame, and this fraction represents network loading. This ensures that network loading is modeled accurately and its effect on system performance can be studied. In this approach, the BS scheduler and MS in interfering cells are not instantiated. However, if wrap-around method is used, the interference is generated dynamically by explicitly modeling all co-channel MS and cells. This method yields a more accurate representation of interference in uplink & downlink, and is recommended for studying interference mitigation techniques.

14 Handoff (informative)

The system simulation defined elsewhere in the document deals with throughput, spectral efficiency, and latency. This section focuses on the methods to study the performance of handover which affects the end-users experience. For parameters such as cell size, DL&UL transmit powers, number of users in a cell, traffic models, and channel models; the simulation follows the simulation methodology defined elsewhere in the document.

The handover procedure consists of cell reselection via scanning, handover decision and initiation, and network entry including synchronization and ranging with a target BS. Latency is a key metric to evaluate and compare various handover schemes as it has direct impact on application performance perceived by a user. Total handover latency is decomposed into several latency elements (see section 14.x.x). Further, data loss rate and unsuccessful handover rate are other important metrics.

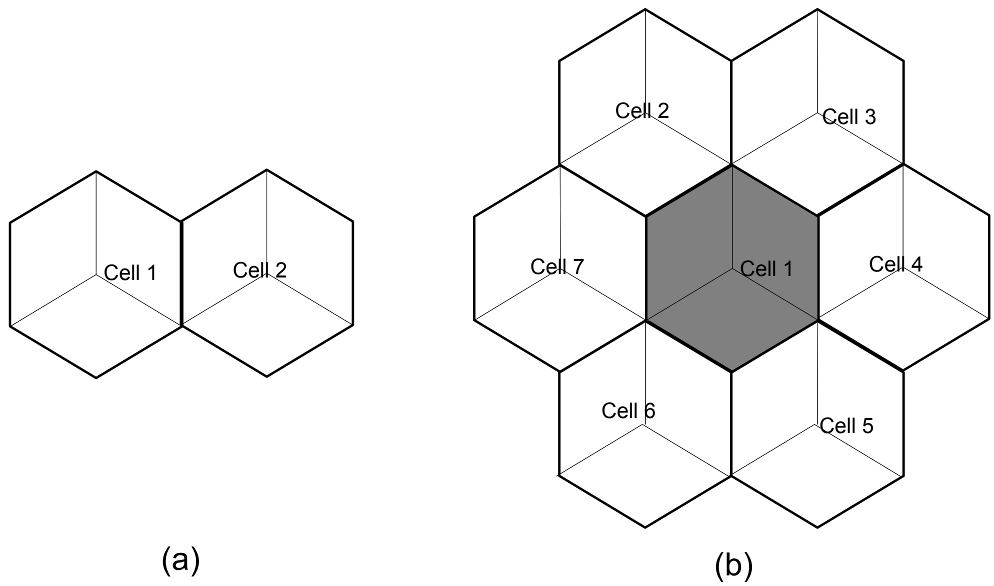

Figure 14-4: a) 2 Cell and b) 7 Cell topology

The simulation scenarios consider 2 cells and 7 cells (first tier) network topologies as shown in Figure 1. For both 2 cell and 7 cell scenarios, the SINR, and RSSI calculations in both serving BS cell and target BS cell contain the interference modeling which is defined in the simulation methodology document. Either one mobile MS with multiple fixed MSs or multiple mobile MSs with multiple fixed MSs may be deployed within these topologies. For simplicity, 2 cell topology with one mobile MS and multiple fixed MSs can be modeled as a baseline. 7 cell topology can be used to evaluate the scenarios in which more than one potential target BSs are involved in the handover procedure. Three trajectory patterns shown in Figure 2, 3, and 4 can model the mobile MSs mobility in the 7 cell topology as well as 2 cell topology. For the 7 cell topology, statistics will be collected only when mobile MSs had handover from or to the center cell (i.e. Cell 1 in Figure 1(b)).

The mobile MSs speeds need to be varying per simulation drop following Table 3.3.1-1 Channel models. The trajectory of the mobile MSs can be chosen from the trajectories shown below.

Trajectory 1

In this trajectory, mobile users move from cell 1 to cell 2 along the arrow shown in Figure 2.

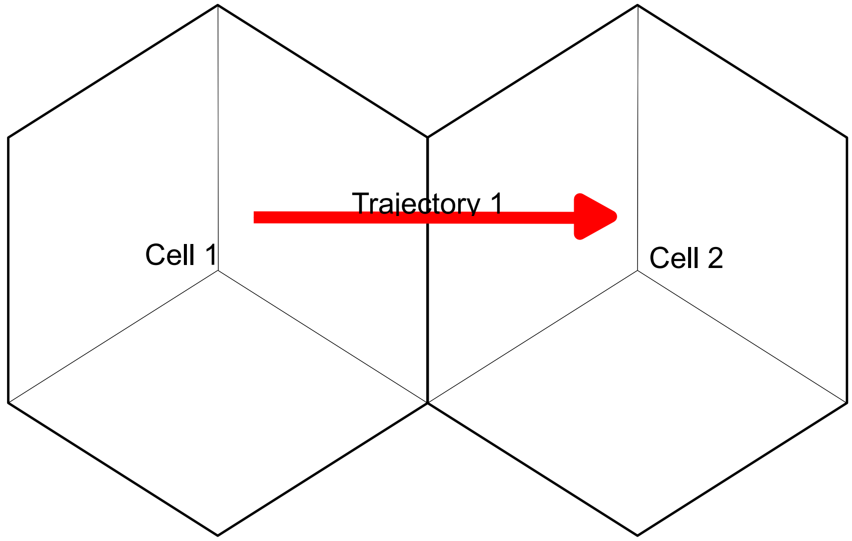

Figure 14-5: Trajectory 1 -> Straight path between BSs [30]

Trajectory 2

In this trajectory, mobile users move along the cell edge as shown in Figure 3.

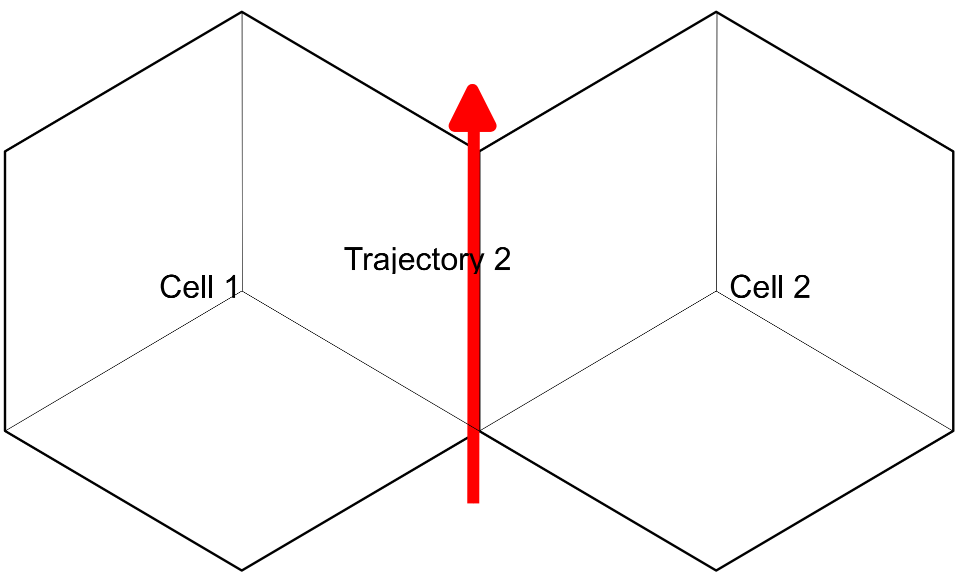

Figure 14-6: Trajectory 2 -> Straight path along the cell edge [30]

Trajectory 3

In this trajectory, mobile users move between the BSs as shown in Figure 4.

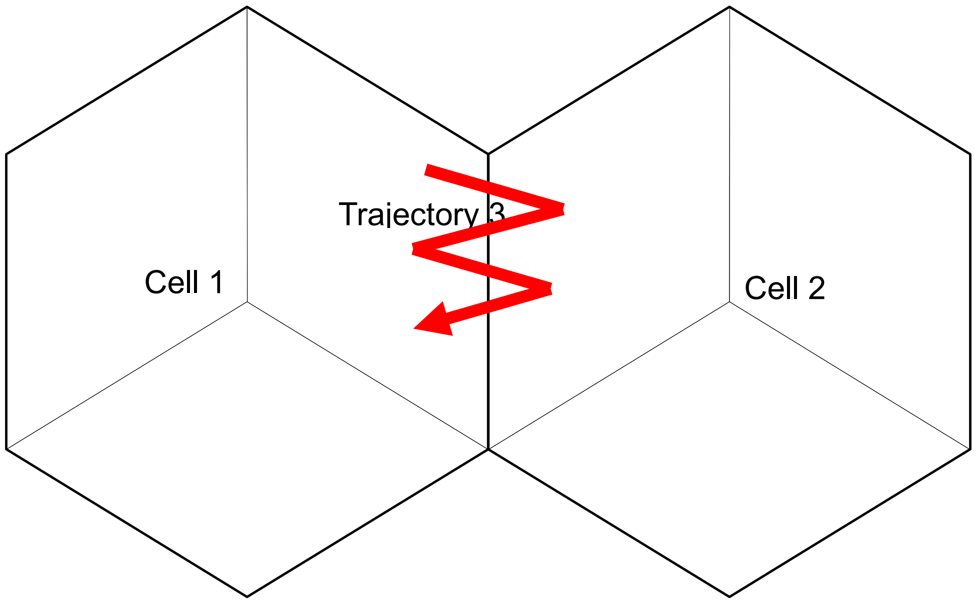

Figure 14-7: Trajectory 3 -> Zigzag path between two BSs

Handover Performance Metrics

The following parameters will be collected in order to evaluate the performance of different handover schemes. All these statistics defined in this section will be collected in relation to the occurrence of handovers. A CDF of each metric may be generated to evaluate a probability that the corresponding metric exceeds a certain value.

For a simulation run, we assume:

Total number of successful handovers occurred during the simulation time = N_{HO}
Total number of failed handover during the simulation time = N_{HO_fail}
Total number of handover attempts during the simulation time = $N_{attempt}$

1- **Radio Layer Latency: Radio Layer Latency:** This value measures the delay between the time instance $T_{1,i}$ that an MS transmits a serving BS its commitment to HO (for a HHO, this is the time that the MS disconnects from the serving BS) and the time instance $T_{2,i}$ that the MS achieves the success of the PHY layer synchronization (i.e., frequency and DL timing synchronization) due to handover occurrence i. The exact thresholds for successful PHY synchronization are for further study. For this metric, the following will be measured.

$$\text{Average Radio Layer Latency} = \frac{\sum_{i=1}^{N_{HO}} (T_{2,i} - T_{1,i})}{N_{HO}}$$

Maximum Radio Layer Latency =

$$\max_{1 \le i \le N_{HO}} [\mathit{Radio\ Layer\ Latency\ of\ handover\ occurrance\ i}]$$

2- **Network Entry Time:** This value represents the delay between an MS's radio layer synchronization at $T_{2,i}$, and its completion of a Layer 2 network entry procedure at $T_{3,i}$ due to handover occurrence i. This consists of ranging, UL resource request processes (contention or non-contention based), negotiation of capabilities, and registration. All HO MAC messages success/failure rates must be consistent with the packet error rate used for data.

Average Network Entry Time = $\frac{\sum_{i=1}^{N_{HO}} (T_{3,i} - T_{2,i})}{N_{HO}}$

Maximum Radio Layer Latency =

$$\max_{1 \le i \le N_{HO}} [\mathit{Network\ Entry\ Time\ of\ handover\ occurance\ i}]$$

3- **Connection Setup Time:** This value represents the delay between the completion of Layer 2 network entry procedure at $T_{3,i}$ and the reception of first data packet from new BS (target BS) at $T_{4,i}$ due to handover occurrence i.. This consists of DL-UL packet coordination and a path switching time. A path switching time, as a simulation input parameter, may vary depending on network architecture.

Average Connection Setup Time = $\frac{\sum_{i=1}^{N_{HO}} (T_{4,i} - T_{3,i})}{N_{HO}}$

Maximum Radio Layer Latency =

$$\max_{1 \le i \le N_{HO}} [\mathit{Connection\ Setup\ Time\ of\ handover\ occurance\ i}]$$

4- **Service Disruption Time:** This value represents time duration that a user can not receive any service from any BS. It is defined as the sum of Radio Layer Latency, Network Entry Time and Connection Setup Time due to handover occurrence i..

Average Service Disruption Time = Average Radio Layer Latency + Average Network Entry Time + Connection Setup Time

Maximum Service Disruption Time =

$$\max_{1 \le i \le N_{HO}} [\mathit{Service\ Disruption\ Time\ of\ handover\ occurance\ i}]$$

6- **Data Loss**: This value represents the number of lost bits during the handover processes. $D_{RX,i}$ and $D_{TX,i}$ denotes the number of received bits by the MS and the number of total bits transmitted by the serving and the target BSs during the MS performs handover occurrence *i,* respectively. Traffic profiles used for the simulation experiments to compare different handover schemes need to be identical.

$$\text{Data Loss} = \frac{\sum_{i=1}^{N_{HO}} \left(D_{TX,i} - D_{RX,i} \right)}{N_{HO}}$$

6- **Handover Failure Rate:** This value represents the ratio of failed handover to total handover attempts. A failed handover happens if a handover is executed while the reception conditions are inadequate.

$$\text{Handover Failure Rate} = \frac{N_{HO\_fail}}{N_{attempt}}$$

15 Power Management (informative)

The objective of power management is to minimize the power consumption by the subscriber stations (MSs) and thus, to maximize the battery life of the mobile devices. This is achieved through the use of idle mode and sleep mode operations. While idle mode is designed to use the periods of inactivity between calls to save battery power, the sleep mode is designed to use the periods of inactivity in between packets bursts of a call to reduce power consumption by the mobile devices. Thus, the simulation methodology should model sleep and idle mode operations. In addition, it should provide means to investigate the performance of idle and sleep mode operations. For example, some of the critical performance parameters to evaluate the power management in such networks are as follows: the duty cycle of idle and sleep mode operations; time it takes for an MS to return to active from idle and sleep mode. The details of these parameters are FFS.

16 Simulation Procedure and Flow

Downlink

Center Cell Method

1. The system is modeled as a network of 19 hexagonal cells each with 3 sectors.
2. MSs are first dropped randomly throughout the system such that the distance of the MS from the BS is at least 35m from the BS. Each mobile corresponds to an active user session that runs for the duration of the drop.
3. Sector assignment is based on the received power at an MS from all potential serving sectors. The sector with best path to MS, taking into account slow fading characteristics (path loss, shadowing, and antenna gains) is chosen as the serving sector. Each user is assigned to only one sector.
4. Mobile stations are randomly dropped over the 57 sectors such that each sector has the required numbers of users. All sectors of the system shall continue

accepting users until the desired fixed number of assigned users per sector is achieved in all sectors.

5. MSs are assigned channel models with the given probabilities.
6. The signal and interference are computed for each MS by considering the propagation model and assigned channel models.
7. Packet calls arrive as per the traffic mix and traffic models of section. Packets are not blocked when they arrive into the system (i.e. queue depths are infinite).
8. Packets are scheduled with a packet scheduler using the proportional fairness metric. Channel quality feedback delay, PDU errors and ARQ are modeled and packets are retransmitted as necessary.
9. Simulation time is chosen to ensure convergence in desired performance metrics.
10. Performance statistics are collected only for MSs in the center cell.
11. All 57 sectors in the system shall be dynamically simulated.

Wrap-around Method

As described in Section , the network topology shall be implemented with cell wrap around.

1. The system is modeled as a network of 19 hexagonal cells each with 3 sectors MSs are first dropped randomly throughout the system such that the distance of the MS from the BS is at least 35m from the BS. Each mobile corresponds to an active user session that runs for the duration of the drop.
2. MSs are first dropped randomly throughout the system such that the distance of the MS from the BS is at least 35m from the BS. Each mobile corresponds to an active user session that runs for the duration of the drop.
3. MS's sector assignment is based on the received power at an MS from all potential serving sectors. The sector with best path to MS, taking into account slow fading characteristics (path loss, shadowing, and antenna gains) is chosen as the serving sector. Each user is assigned to only one sector.
4. Mobile stations are randomly dropped over the 57 sectors such that each sector has the required numbers of users. All sectors of the system shall continue accepting users until the desired fixed number of assigned users per sector is achieved in all sectors.
5. MSs are assigned channel models with the given probabilities.
6. The signal and interference are computed for each MS by considering the propagation model and assigned channel models.
7. Packet calls arrive as per the traffic mix and traffic models of section. Packets are not blocked when they arrive into the system (i.e. queue depths are infinite).
8. Packets are scheduled with a packet scheduler using the proportional fairness metric. Channel quality feedback delay, PDU errors and ARQ are modeled and packets are retransmitted as necessary.
9. Simulation time is chosen to ensure convergence in desired performance metrics.
10. Performance statistics are collected for MSs in all 19 cells.
11. All 57 sectors in the system shall be dynamically simulated.

Uplink

TBD

Calibration

TBD

17 Traffic Models

Described in a separate contribution

18 Simulation Outputs and Performance Metrics

Described in a separate contribution

19 Template for Reporting Results

The link-level and system-level simulation results shall be reported in the format exemplified in the following tables and graphs . Where applicable, one table and figure per simulation case should be provided. Models and assumptions should be aligned with those listed in this document. Any deviations should be highlighted. Link level results should be presented as in Figure 19-12.

Metric	Peak Rate (Mbps)	C-plane latency (ms)	U-plane delay (ms)	Intra- FA HO delay (ms)	Inter-FA HO delay (ms)
IEEE 802.16e Reference System					
IEEE 802.16m DL					
IEEE 802.16m UL					

Table 19-14: System Analysis Results

Metric	Average cell throughput and spectrum efficiency (x IEEE 802.16e Reference System)	Average user throughput and spectrum efficiency	Cell-edge user throughput and spectrum efficiency
IEEE 802.16e Reference System			
IEEE 802.16m baseline SU-MIMO			
IEEE 802.16m baseline MU-MIMO			
IEEE 802.16m			
IEEE 802.16m			

Table 19-15: Downlink full buffer system evaluation

Metric	Average cell throughput and spectral efficiency (x IEEE 802.16e Reference System)	Average user throughput and spectral efficiency	Cell-edge user throughput and spectral efficiency
IEEE 802.16e Reference System			
IEEE 802.16m baseline			
IEEE 802.16m MU-MIMO			
IEEE 802.16m SU-MIMO			
IEEE 802.16m …			

Table 19-16: Uplink full queue system evaluation results.

Metric	VoIP Capacity
IEEE 802.16m DL	
IEEE 802.16m UL	

Table 19-17: VoIP Results

Metric	System throughput and spectrum efficiency	Max ISD
802.16e Reference System MBS-SFN		
802.16m MBS-SFN		

Table 19-18: MBS-SFN results.

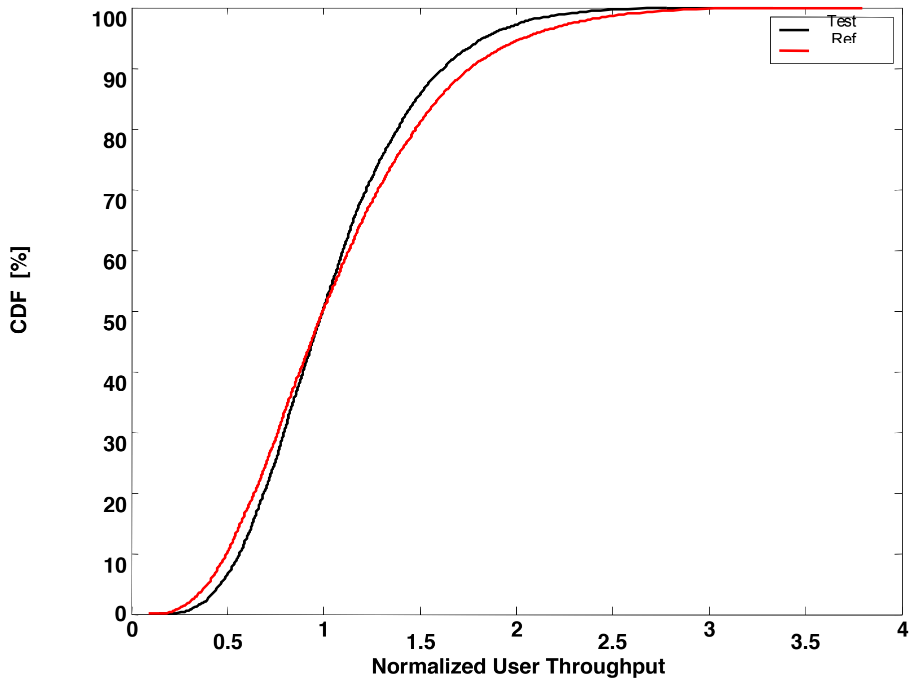

Figure 19-8: Example Result - Downlink normalized user throughput CDF

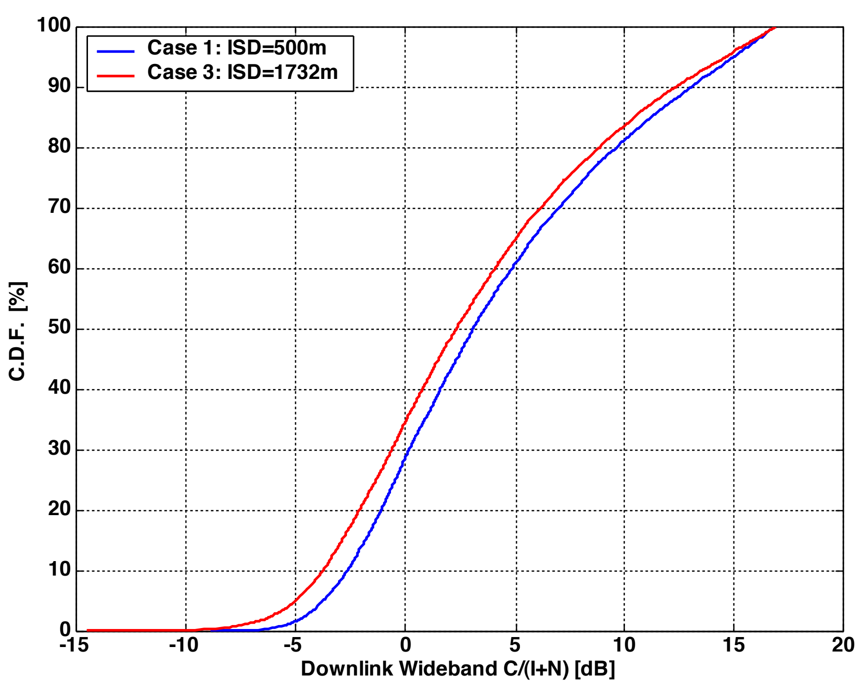

Figure 19-9: Example Result - Downlink geometry distribution

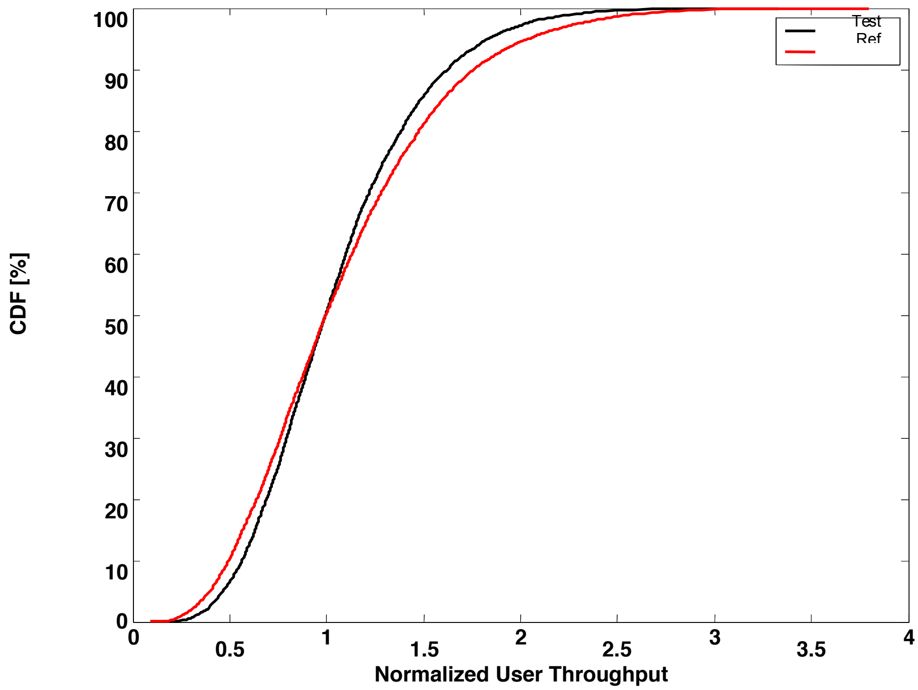

Figure 19-10: Example Result - Uplink normalized user throughput

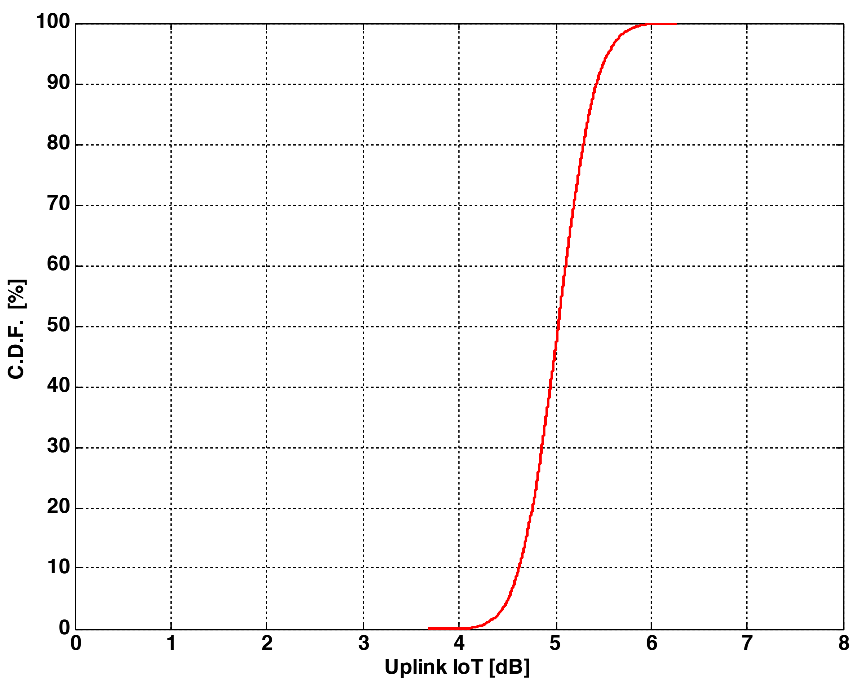

Figure 19-11: Example Result - Uplink Interference over Thermal (IoT) distribution

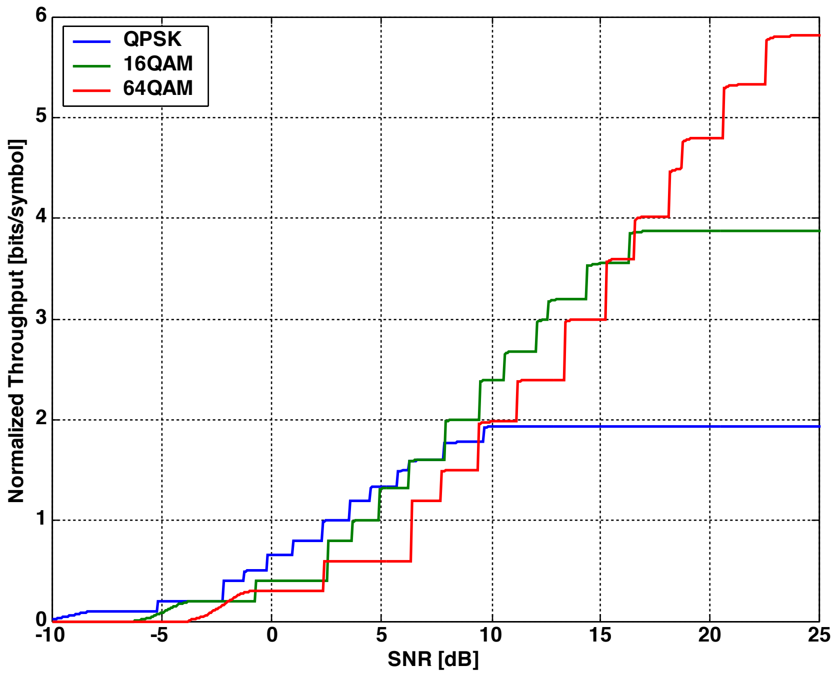

Figure 19-12: Example Result - Normalized throughput vs. SNR for AWGN channel.