Project	IEEE 802.16 Broadband Wireless Access Working Group <**http://ieee802.org/16**>
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Re:	Response to a call for contributions for the Relay TG, see C80216j-06/001.pdf
Abstract	This document captures scope of the Multi-hop System Evaluation Methodology including the Channel Model, Traffic Model and Performance Metrics.
Purpose	System Evaluation Methodology including the Channel Model, Traffic Model and Performance Metrics documented in this contribution is used as a reference for the performance evaluation for the IEEE802.16j Task Group.
Notice	
Release	

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4 Performance Metrics

The performance metrics are divided into two categories. They are:

Single-user performance; and

Multi-user performance.

Examples of single-user performance metrics are the link budget margins, C/I area coverage and data rate area coverage. These metrics are evaluated assuming that a single user is in a particular cell area utilizing all the resources in that cell while external interference may be evaluated assuming that at least a single active user is available in the external cell (for both forward and UL). These metrics are not end-to-end performance metrics and therefore, could be evaluated without modeling higher layer protocols and is independent of applications.

However, when multiple users are in the system the system resources have to be shared and a user's average data rate will be smaller than the single-user rate. Therefore, multi-user metrics are proposed which show how a system behaves under a multi-user environment.

In order to evaluate multi-user performance accurately, scheduling and higher layer traffic behaviors and protocols need to be modeled. However, simulation run times can be prohibitively large. Specially, in the case of multihop systems, each sector can have several relay stations and there are a large number of relay stations and relay to user and relay to base links need to be modeled sand simulated. Therefore, such simulations can be very CPU intensive. Therefore, we suggest that initial design validations be done using a simple but representative analysis using a full queue traffic without modeling higher layers. These are described under multi-user performance metrics.

4.1 Single-user performance Metrics

Note that the area coverage mentioned below is equivalent to the percentage of users meeting a given requirement when the users are uniformly distributed in the interested geographical area.

4.1.1 Link Budget and Coverage Range (Noise Limited) – single-cell consideration

Link budget evaluations is a well known method for initial system planning and this needs to be carried out for ~~relay~~ RS to ~~base~~BS, ~~relay~~ RS to ~~user~~ MS and ~~base~~ BS to ~~user~~ MS links separately. The parameters to be used needs to be agreed upon after obtaining consensus. Using the margins in the link budget, the expected signal to noise ratio can be evaluated at given distances. Using these results, the noise limited range can be evaluated for the system when the relays are deployed. Link budget template from ITU-R M.1225 [15] is modified, which ~~Link budget analysis~~ are provided in detail in ~~Section 5~~Appendix B.

Since relays can be used to extend the range covered by a cell under noise limited environment (i.e. ~~no~~ negligible interference from other cells but the limitation coming from the fact that the transmit power is not enough to provide a sufficient signal strength above thermal noise) coverage range is a metric of importance in such cases.

Coverage range is defined as the maximum radial distance to meet a certain percentage of area coverage (x%) with a signal to noise ratio above a certain threshold (target_snr) over y% of time, assuming no interference signals are present. It is proposed that x be 99 and y be 95.

4.1.2 C/I Coverage – interference limited multi-cell consideration

The C/I coverage is defined as the percentage area of a cell where the average C/I experienced by a stationary user is larger than a certain threshold (target_ci).

4.1.3 Data Rate Coverage – interference limited multi-cell consideration

The percentage area for which a user is able to transmit/receive successfully at a specified mean data rate using single-user analysis mentioned above. No delay requirement is considered here.

4.2 Multi-user Performance Metrics

4.2.1 ~~Combined Coverage and Capacity Metric (cc)~~

~~There are three important aspects that need to be considered when the multi-user performance is evaluated for a multi-hop system.~~

4.2.1.1.1 ~~Sharing the shared channel among users:~~

Although a user may be covered for a certain percentage area (e.g. 99%) for a given service, when multiple users are in a sector/BS, the resources (time, frequency, power) are to be shared ~~with~~ amongother the users. It can be expected that a user's average data rate may be reduced by a factor of N when there are N active users (assuming resources are equally shared and no multi-user diversity gain), compared to a single user rate.

For example, assume that there is a system, where a shared channel with a peak rate of 2 Mbps can serve 99% of the area. If a user wants to obtain a video streaming service at 2 Mbps, that particular user will be able to obtain the service, but no other user will be able to get any service during the whole video session (which may extend for more than an hour). Therefore, in this example although 99% area is covered for the video service, this service is not a viable service for the operator. Coverage performance assessment must be coupled with capacity (# of MSs), to obtain a viable metric.~~and performance of coverage need to be coupled with the capacity in order to reflect viable service solutions..~~

The ~~low rate~~ users having poor channel quality ~~can~~may be provided more resources so that they would get equal service from the cellular operator. This could adversely ~~but that would~~ impact the total cell throughput~~capacity~~. Thus, there is a trade-off between coverage and capacity. ~~and a~~Any measure of capacity should be provided with the associated coverage. .

Since an operator should be able to provide the service to multiple users ~~in~~ at the same time, an increase in the area coverage itself does not give an operator the ability to offer a given service.

Therefore, the number of users that can be supported under a given coverage captures actual coverage performance ~~of~~ for a given service from a viability point of view.

The suggested performance metric is the number of admissible users (capacity), parameterized by the service (Rmin), and the coverage (allowable outage probability).

4.2.2 Combined Coverage and Capacity Metric (cc)

~~Combined Coverage and Capacity Index (*CC*):~~ The number *N* of simultaneous users per cell (e.g. MMR-cell or legacy cell) that can be supported achieving a target information throughput $R\min$ with ~~a specified~~specified coverage reliability.
This performance metric can be approximated using either a simplified approximate evaluation methodology or a more detailed simulation as described below. Both methods are useful since the approximation methodology can be used to quickly compare two coverage enhancement techniques ~~at~~ during the initial system concept development stage. The detailed simulations are useful to evaluate more carefully the most promising concepts. When results are presented the evaluation method used should be reported.

4.2.3 Method 1: ~~Method 1:~~Simplified Combined Coverage and Capacity Index Evaluation

This is a Simplified Methodology to evaluate Combined Coverage and Capacity Index (cc) using only the rate capability of each user. This can be evaluated without modeling higher layer protocols.

Assume~~,~~ that in a simulation ~~that number of~~N users are dropped uniformly in the service area. Let the required coverage for a given service ~~is~~ be x% and the required information rate for that service ~~is~~ be Rmin. The first step in evaluating *cc* is to ~~take out the lowest (100-x)% of users out of the evaluation~~sort he MSs in descending order of achievable rate, assuming each utilizes the entire resources. Then, only the top x% of the MSs are considered. Assume the number of users in the remaining group is *k*, and the ~~average effective~~ data rate capability of user i ~~that can be supported by the ith user~~ is r_i (i = 1 to ~~N~~N) by using a scheduler that provides equal throughput to all the serviced users.~~.~~

Then,

if the ~~min(~~r_{ik}~~)~~ < Rmin, $cc = 0$ (i.e. indicating that the service cannot be provided with the required coverage, regardless of the number of users).

Else, $$cc = \frac{k}{\sum_{i=1}^{k} \frac{R\min}{r_i}}$$.~~,~~

Letting N become large, *cc* approaches the expected ~~this is the maximum #~~value of the number of users that can be supported by the system for that service with the given coverage (i.e. x%).

If a user communicates directly with BS, r is its effective rate to BS.

4.2.4 Method 2: Detailed Combined Coverage and Capacity Index Evaluation

~~Method 2:~~

The following is a more detailed methodology to evaluate the combined coverage and capacity metric.

Coverage reliability for a particular system (cell radius, shadow fading environment, relay station placement, and so on) with a particular number of users n each requiring information throughput $R\min$ is calculated using a static system simulator. The static simulator shall model all other-user interference affects using appropriate path loss models and power control models (if any). The static simulator shall model a scheduler and resource manager that allocates resources to as many users as possible and all relays supporting those users such that the target information throughput ~~is~~ $R\min$ is achieved. Bandwidth is shared by the BS and RSs, while the BS and each RS have their own power resource. The static system simulator is run repeatedly with each run modeling a different instance of random drops of n MSs. Each simulator run results in $n_{s,i}$ MSs being served with the required information throughput and $n_{b,i}$ MSs being blocked due to insufficient carrier to interference plus noise ratio and/or insufficient time-frequency (or power) resources. $n = n_{b,i} + n_{s,i}$. In this equation, i is an index identifying a particular simulation run. Coverage reliability is a function of n and is:

$$\frac{1}{M \cdot n}\sum_{i=1}^{M} n_{s,i}$$

where M is the total number of simulation runs. The Combined Coverage and Capacity Index ~~N~~ *cc* is the largest n for which

$$\frac{1}{M \cdot n}\sum_{i=1}^{M} n_{s,i} \geq x$$

4.3 Definitions of Performance Metric

4.3.1 System data throughput

The data throughput of a MMR-BS is defined as the number of information bits per second that a site can successfully deliver or receive using the scheduling algorithms.

4.3.2 Packet call throughput:

Packet call throughput which is the total bits per packet call divided by total packet call duration.

4.3.3 Effective system spectral efficiency

Effective system spectral efficiency normalized by the downlink/uplink ratio of TDD system, for the DL case:

$$\text{DL Site Spectral Efficiency} \quad \frac{\text{DL System Data Throughput}}{\text{Total Site BW allocated to DL}}$$

4.3.4 CDF of data throughput per user

The throughput of a user is defined as the ratio of the number of information bits that the user successfully receive~~s~~d divided by the amount of time the user was actively involved in data packet transfer.~~during a simulation run and the simulation time.~~

4.3.5 The CDF of packet delay per user

CDF of the packet delay per user provides a basis in which maximum latency, x%-tile, average latency as well as jitter can be derived.

4.3.5.1 Maximum MMR Packet Latency

The maximum MMR packet latency is defined as the maximum interval between packets originated at the source station (either MS or BS) and received at the destination station (either BS or MS) in an MMR system for a given packet call duration.

4.3.5.2 X%-tile MMR Packet Latency

The x%-tile MMR packet latency is simply the packet latency number in which x% of packets have latency below this number.

4.3.5.3 Average MMR Packet Latency

The average MMR packet latency is defined as the average interval between packets originated at the source station (either MS or BS) and received at the destination station (either BS or MS) in an MMR system for a given packet call duration.

4.3.5.4 Jitter

This parameter defines the maximum delay variation (jitter) for the packets of a given packet call duration in an MMR system.

4.3.6 Packet Loss Ratio

The packet loss ratio per user is defined as:

$$Packet\ Loss\ Ratio = \frac{Total\ Number\ of\ Successfully\ \mathrm{Re}ceived\ Packets}{Total\ Number\ of\ Successfully\ Transmitted\ Packets}$$

Typically for a VoIP application, 2% packet loss ratio is tolerable. For gaming and video streaming applications, packet loss ratio is typically less than 1%. Both the single link packet latency and the packet loss ratio per user are important performance metrics for assessing different QoS schemes.

4.4 Fairness Criteria

Since one of the primary objectives of the introduction of relays is to have uniform service coverage resulting in a fair service offering for best effort traffic, a measure of fairness under best effort assumption is important in assessing how well the relaying solutions perform.

The fairness is evaluated by determining the normalized cumulative distribution function (CDF) of the per user throughput. The CDF is to be tested against a predetermined fairness criterion under several specified traffic conditions. The same scheduling algorithm shall be used for all simulation runs. That is, the scheduling algorithm is not to be optimized for runs with different traffic mixes. The owner(s) of any proposal are also to specify the scheduling algorithm.

Let $T_{put}[k]$ be the throughput for user k. The normalized throughput with respect to the average user throughput for user k, $\widetilde{T}_{put}[k]$ is given by

$$\widetilde{T}_{put}[k] = \frac{T_{put}[k]}{\underset{i}{\mathrm{avg}}\, T_{put}[i]}.$$

4.4.1 Fairness Index

Since CDF does not provide a quantitative measure of fairness it is important to define a metric to measure fairness. Since fairness of a system can be increased by providing more resources to low rate users which result in a reduction of the system capacity, when performance is measured it is important to specify the associated fairness. Then, the performance of two systems can be compared under same fairness conditions. For this purpose, fairness index of a resulting throughput distribution is defined as,

$$\text{Fairness Index (FI)} = e^{-\sigma}$$

where σ is the standard deviation of the normalized per user throughput distribution.

Note that higher the FI higher is the fairness of a system and FI =1 corresponds to the case where all the users receive same throughput.

Depending on the service type and test case being simulated, different fairness requirements may be specified. Three such fairness criteria are specified in this document for this purpose. The evaluation methodology should specify what fairness criterion has to be met for a given test case.

Equal Throughput Criterion:

To have a reasonably compromise fairness as specified to meet a CDF requirement.

To meet a specified level of fairness

4.4.2 Equal Throughput or Full Fair Criterion:

To satisfy equal throughput requirement, all the users who are admitted to the system should get equal per user throughout if they have same amount of traffic to send/receive. In a full queue scenario, where traffic is assumed to be always available for transmission, the equal throughput requirement can be achieved by allocating time slots to users, such that the time allocated during a certain period for that user is inversely proportional to the data rate capability of the user.

If the data rate capability of the ith user is *r(i)*, under the equal throughput criterion, time allocated to each user should be proportional to 1 / *r(i)* (assuming equal input traffic).

The resulting equal aggregate throughput is, $$C = \frac{1}{\sum_{i=1}^{n} 1/(r(i)}$$

Since one of the primary objectives of relays is to provide uniform service offering across users, the total aggregate throughput under equal throughput criterion, is a good metric to compare two systems.

4.4.3 Moderately Fair Solution :

The CDF of the normalized throughputs with respect to the average user throughput for all users is determined. This CDF shall lie to the right of the curve given by the three points in 0.

Table 1 Criterion CDF

Normalized Throughput w.r.t average user throughput	CDF
0.1	0.1
0.2	0.2
0.5	0.5

4.4.4 Fairness Criterion to meet a Specified Fairness Index

Under this fairness criterion, the fairness index of the normalized per user throughput should be higher than a target value. This target value is to be specified under each test case. i.e., the fairness requirement is,

Fairness Index of the resulting distribution > target_fairness_index.

5 References

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

Appendices

A.1 Multi-Cell Layout

In Figure 6, a network of cells is formed with 7 clusters and each cluster consists of 19 cells. Depending on the configuration being simulated and required output, the impact of the outer 7 clusters may be neglected. In those cases, only 19 cells and associated relays may be modeled. These cases are identified in the sections below. For the cases where modeling outer-cells are necessary for accuracy of the results, the 7 cluster network can be used. However, the six of the seven clusters are just virtual clusters repeating the middle cluster in its surroundings as shown in the figure. Each cell with generic hexagonal grid is separated to 3 sectors, each is formed by a panel directional antennas.

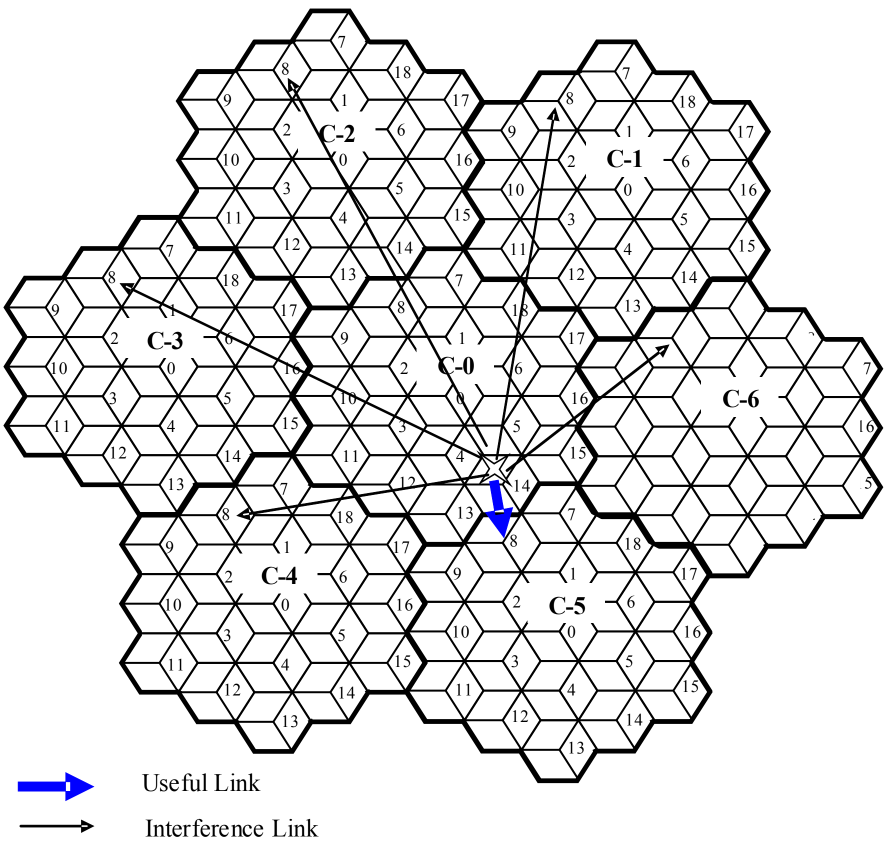

Figure 1 Multi-cell Layout and Wrap-around Example

A1.1 Obtaining virtual MS locations

The number of MSs is predetermined for each sector, where each MS location is uniformly distributed. The MS assignment is only done in the cluster-0 from where the decided MSs are replicated in the other six clusters. The purpose to employ this wrap-around technique, as will be discussed in later section, is to easily model the interferences from other cells.

A1.2 Determination of severing cell for each MS in a wrap-around multi-cell network

The determination of serving cell for each MS is carried out by two steps due to the wrap-around cell layout; one is to determine the shortest distance cell for each MS from all seven logical cells, and the other is to determine the severing cell for each MS based on the strongest link among 19 cells related to the path-loss and shadowing.

To determine the shortest distance cell for each MS, the distances between the target MS and all logical cells should be evaluated and select the cell with a shortest distance in 7 clusters. Figure 2 illustrates an example for determination of the shortest distance cell for the link between MS and cell-8. It can be seen that the cell-8 located in cluster-5 generates the shortest distance link between MS and cell-8.

To determine the severing cell for each MS, we need to determine 19 links, whereby we may additionally determine the corresponding path-loss, shadowing and transmit/receive antenna gain in consideration of antenna pattern. The serving cell for each MS should offer a strongest link with a strongest received long-term power. It should be noted that the shadowing experienced on the link between MS and cells located in different clusters is the same.

B Link Budget

The link budget can be divided into two parts: The system gain reflects the performance of the transmitter and receiver, including aspects such as antenna gain and receiver sensitivity. The following link budget template in ITU-R M.1225 [15] with slight modifications is given in Table below. Entries that have explicit example numerical values in the table (such as power levels, cable losses, etc) should be used to support system level simulations. The values provided for RS antenna gain are just as an example and should be adjusted based on the antenna used in simulation.

Item	**Downlink**	**Uplink**
(a1) Maximum transmitter power (on the N_{Used} subcarriers)	dBm	dBm
(b) Cable, connector, and combiner losses (enumerate sources)	3 dB for BS 1 dB for RS	0 dB for MS 1 dB for RS
Body Losses	0 dB for both RS and BS	3 dB for MS 0 dB for RS
(c) Transmitter antenna gain	17 dBi for BS 11 dBi for RS	0 dBi for MS 11 dBi for RS
(d1) **Transmitter e.i.r.p. _ (a1 – b _ c)**	dBm	dBm
Penetration Loss (Ref: 3GPP2) [Determine how to use these numbers for different environments, revisit if 20dB is a reasonable value for building penetration)]	20 dB (Building) 10 dB (Vehicular)	20 dB (Building) 10 dB (Vehicular)
(e) Receiver antenna gain	0 dBi e.g., 11 dBi for RS	17 dBi for BS 11 dBi for RS
(f) Cable and connector losses	0 dB for MS 1 db for RS	3 dB for BS 1 dB for RS
Body Losses	3 dB for BS 0 dB for RS	0 dB for both RS and BS
(g) **Receiver sensitivity**	Refer to Equation (149b) in 802.16e-2005	Refer to Equation (149b) in 802.16e-2005
(h) Hand-off gain	dB	dB
(i) Explicit diversity gain	dB	dB
(j) Other gain	dB	dB
(k) Log-normal fade margin	dB	dB
(l) **Maximum path loss** **_ {d1 – g _ (e – f) _ i _ h _ j – k}**	dB	dB
(m) Maximum range	m	M

~~Link Budget should include all the key items defined below~~

~~Si = Pout + Gt - $A_{Backoff}$ - Pl - Ls + Gr - Ml + Fm~~

~~**Pout** Output power of transmitter in dBm~~
~~**Gt** Transmitting antenna gain in dBi~~
~~**$A_{Backoff}$** Amplifier Backoff~~
~~**Pl** Path loss in dB~~
~~**Ls** Shadowing loss in dB~~
~~**Gr** Receiving antenna gain in dBi~~
~~**Ml** Miscellaneous losses (include cable losses, nonlinearity, body loss, polarization mismatch, other losses etc.)~~
~~**Fm** Fade Margin in dB~~

~~**Si** Received power level at receiver input in dBm~~