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Draft 802.20 Permanent Document

<802.20 Evaluation Criteria – Ver 06>

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<802.20 Evaluation Criteria>

1 Overview

1.1 Scope

This document describes the evaluation criteria used by the IEEE 802.20 working group to evaluate different candidate air interface proposals for the IEEE 802.20 standard. This document and the IEEE 802.20 requirements document form the basis for decisions.

Although the IEEE 802.20 standard defines operations at the Link and Physical layer of the ISO Model, many of the criteria in this document extend to other ISO layers. The evaluation criteria based on other ISO layers are for information use only. Informational areas of this document are used when other methods are insufficient to determine an alternative.

1.2 Purpose

This document presents the criteria used for the evaluation of air interface (i.e. combined MAC/PHY) proposals for the future 802.20 standard. As such, the evaluation criteria emphasize the MAC/PHY dependent IP performance of an 802.20 system.

An “802.20 system” constitutes an 802.20 MAC/PHY airlink and the interfaces to external networks for the purpose of transporting broadband IP services.

1.3 Organization of the Document

2 Link level and System Level Analysis

A great deal can be learned about an air interface by analyzing its airlink to a single user. For example, a *link-level* analysis can reveal the system’s noise-limited range, peak data rate, maximum throughput, and the maximum number of active users. Extension of the link-level analysis to a multi-user single-cell setting is generally straightforward and provides a mechanism for initial understanding of the multiple-access (MAC) characteristics of the system. Ultimately, however, quantifying the *network-level* performance of a system, i.e. system level performance, although difficult, carries with it the reward of producing results that are more indicative of the viability of the system and its expected worth to a service provider.

Since system level results vary considerably with the propagation environment, the number and spatial distribution of users loading the network, and many other fixed and stochastic factors, the assumptions and parameters used must be reported carefully lest the quoted network-level performance be misleading.

Given the charter of 802.20 as a mobile broadband wide area system, it is important to understand the system’s performance in a network setting where multiple base stations serve a large mobile customer base. In a macro-cellular deployment as required by the PAR, multiple basestations are required to cover a geographic region. In practice, cell radii may range from 0.5 km to 15 km. The proposed systems must

cope with the considerable effects of intra-cell and inter-cell interference that arise in network deployments.

Ultimately, the system level performance is the key metric that will drive much of the system level economics. For example, while the per-user peak data rate is an important service metric, a more important one is the achievable service level as a function of the network loading. While link-level performance quantifies what is possible, system level performance quantifies what is likely.

3 Link level Modeling

Single user link-level analysis is an analysis of the performance of a single user terminal (UT) in an assumed propagation environment. This is an important metric for understanding the air interface and yields important information about the system including:

- the effectiveness of link-adaptation and power control,
- the noise-limited range,
- the SNR requirements to support various classes of service,
- the tolerance to multipath and fading, and so on.

However, it should be clear that relying solely on link-level performance can lead the working group to drawing erroneous conclusions. Due to variability in the propagation environment and inter-cell interference, single-user link-level analysis cannot be directly extrapolated to network-level performance.

3.1 Modeling assumptions

Modulation and coding schemes are simulated for all channel models described in section 5.

3.2 Performance metrics

FER vs. SINR is the product of link-level simulations. Systems with adaptive modulation should produce a set of curve (one curve per modulation class). A second family of curves is the link-level throughput vs. SINR. This is derived by combining the FER from the first curve with the number of bits/symbol for each of the modulation classes at a fixed FER of 1 percent.

4 System Level Modeling

In order to accurately model the traffic, physical and MAC layer dependencies between the uplink and the downlink, the system simulations include both UL and the DL in a fully duplex fashion in the same simulation run.

[Note: This issue can be revisited later on as more details on the evaluation methodology, channel models, traffic models and proposals become available. At that point, if the full-duplex simulations are determined to be infeasible due to complexity, a simplex approach can be adopted.]

4.1 Cell layout

The system consists of 19 cells, each with an imaginary¹ hexagonal coverage area. The sectorization details are TBD. Mobile stations are uniformly dropped into the 19-cell system.

All 19 cells are simulated using a cell wrap-around technique (See Appendix A) and the statistics are collected from all the cells.

4.1.1 Distribution of users

Most users of wireless systems experience very good link-quality near the base station. For this reason, the distribution of users throughout the network is integral to the quoting of network-level performance results. Absent the desire to highlight specific abilities of an air interface, users should be distributed uniformly throughout each cell of the network.

4.1.2 User usage model

The following user terminal usage parameters must be specified:

- distribution of indoor vs. outdoor users
- mobility profile across the user base

4.2 Fading Models

4.2.1 Slow Fading Model

<Shadow Fading standard deviation and correlation between cell sites etc.>

4.2.2 Fast Fading Model

<Rayleigh and Rician Fading Models etc.>

4.3 Traffic Modeling

4.3.1 Traffic Mix

<Percentage of different Traffic types>

4.3.2 Traffic Models

<Input from Traffic and Channel Models Correspondence Group>

4.4 Higher Layer Protocol Modeling

<Models for protocols other than MAC/PHY. For example, HTTP and TCP models>

¹ The actual coverage areas are determined by propagation, fading, antenna patterns, and other factors.

4.4.1 HTTP Model

4.4.2 TCP Model

Many Internet applications including Web browsing and FTP use TCP as the transport protocol. Therefore, a TCP model is introduced to more accurately represent the distribution of TCP packets from these applications.

4.4.2.1 TCP Connection Set-up and Release Procedure

The TCP connection set-up and release protocols use a three-way handshake mechanism as described in **Figure 1** and **Figure 2**. The connection set-up process is described below:

1. The transmitter sends a 40-byte SYNC control segment and wait for ACK from remote server.
2. The receiver, after receiving the SYNC packet, sends a 40-byte SYNC/ACK control segment.
3. The transmitter, after receiving the SYNC/ACK control segment starts TCP in slow-start mode (the ACK flag is set in the first TCP segment).

The procedure for releasing a TCP connection is as follows:

1. The transmitter sets the FIN flag in the last TCP segment sent.
2. The receiver, after receiving the last TCP segment with FIN flag set, sends a 40-byte FIN/ACK control segment.
3. The transmitter, after receiving the FIN/ACK segment, terminates the TCP session.

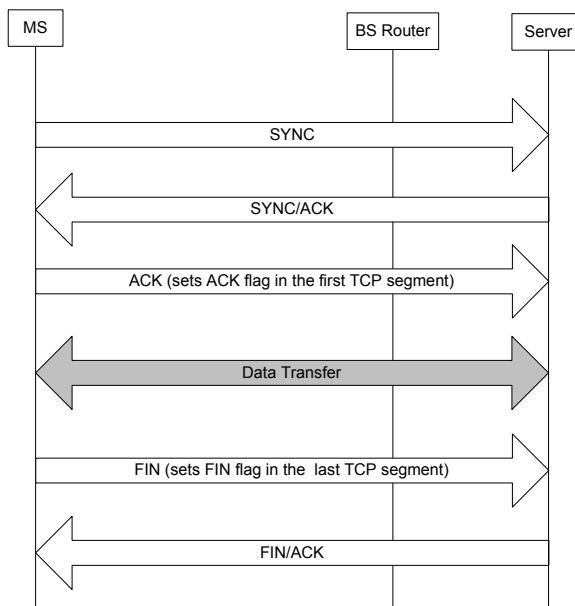


Figure 1: TCP connection establishment and release for Uplink data transfer

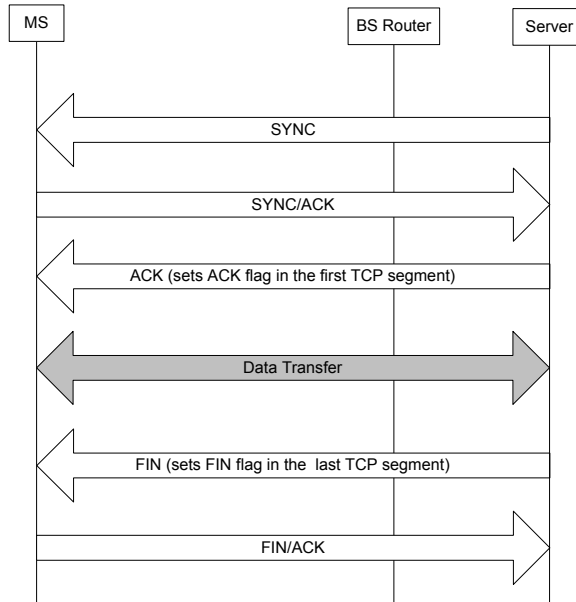


Figure 2: TCP connection establishment and release for Downlink data transfer

4.4.2.2 TCP slow start Model

The amount of outstanding data that can be sent without receiving an acknowledgement (ACK) is determined by the minimum of the congestion window size of the transmitter and the receiver window size. After the connection establishment is completed, the transfer of data starts in slow-start mode with an initial congestion window size of 1 segment. The congestion window increases by one segment for each ACK packet received by the sender regardless of whether the packet is correctly received or not, and regardless of whether the packet is out of order or not. This results in exponential growth of the congestion window.

4.4.2.2.1 UL slow start model

This UL slow start process is illustrated in Figure 3. The round-trip time in Figure 3, τ_{rt} , consists of two components:

$$\tau_{rt} = \tau_u + \tau_l$$

where τ_u = the sum of the time taken by a TCP data segment to travel from the base station router to the server plus the time taken by an ACK packet to travel from the server to the client; τ_l = the transmission time of a TCP data segment over the access link from the client to the base station router. τ_u is further divided into two components; τ_2 = the time taken by a TCP data segment to travel from the base station router to the server plus the time taken by an ACK packet to travel from the server back to the base station router and τ_3 = the time taken by the ACK packet to travel from the base station router to the client.

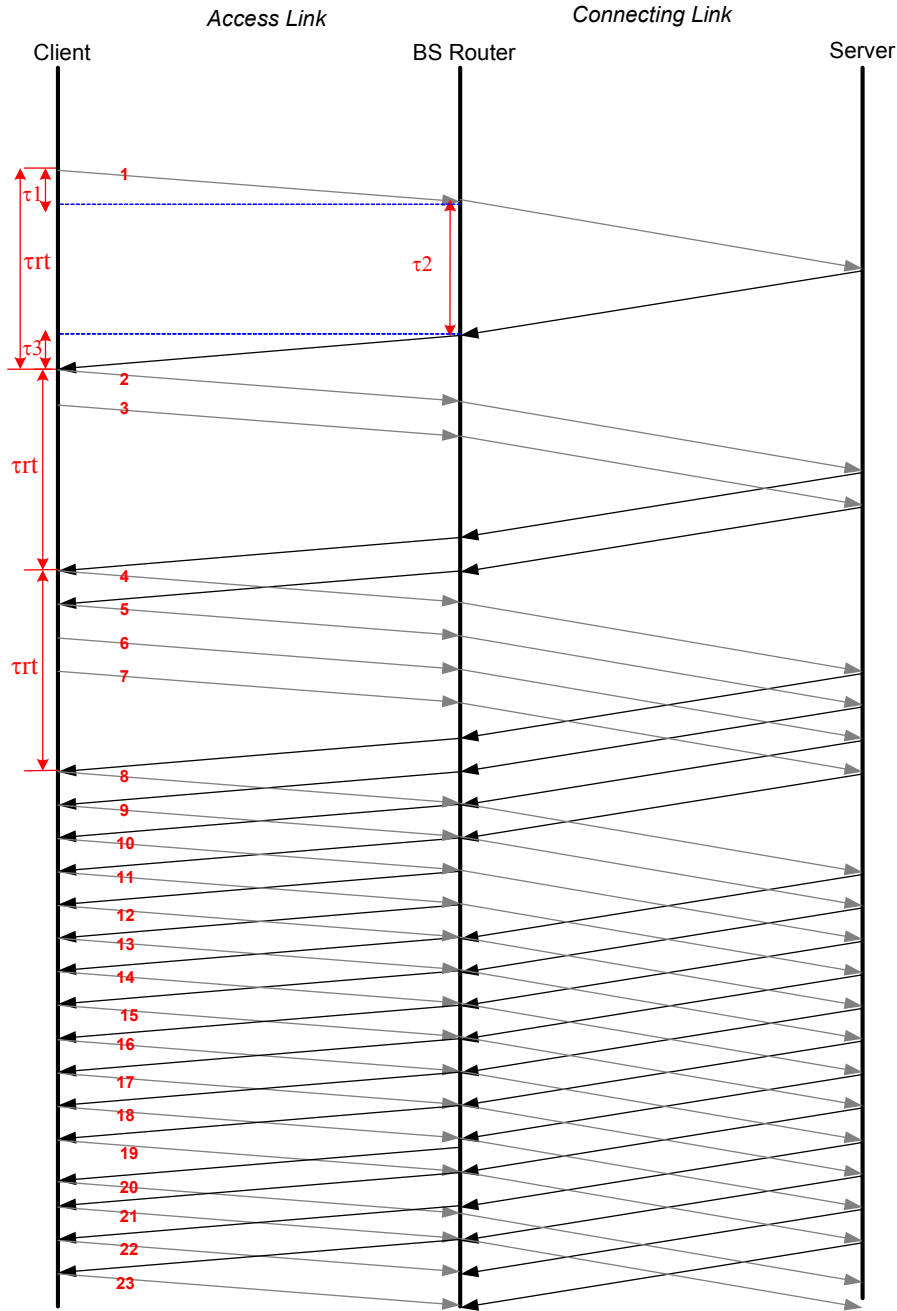


Figure 3: TCP Flow Control During Slow-Start; τ_1 = Transmission Time over the Access Link (UL); τ_{rt} = Roundtrip Time

Table 1 Delay components in the TCP model for the UL upload traffic

Delay component	Symbol	Value
The transmission time of a TCP data segment over the access link from the client to the base station router.	τ_1	Determined by the access link throughput
The sum of the time taken by a TCP data segment to travel from the base station router to the server and the time taken by an ACK packet to travel from the server to the base station router.	τ_2	See 4.5.1
The time taken by a TCP ACK packet to travel from the base station router to the client.	τ_3	See 4.5.1

4.4.2.2 DL slow start model

This DL slow start process is illustrated in Figure 4. The round-trip time in Figure 4, τ_{rt} , consists of two components:

$$\tau_{rt} = \tau_d + \tau_4$$

where τ_d = the sum of the time taken by an ACK packet to travel from the client to the server and the time taken by a TCP data segment to travel from the server to the base station router; τ_4 = the transmission time of a TCP data segment over the access link from the base station router to the client. τ_d is further divided into two components; τ_5 = the time taken by a TCP ACK to travel from the base station router to the server plus the time taken by a TCP packet to travel from the server back to the base station router and τ_3 = the time taken by the TCP packet to travel from the base station router to the client.

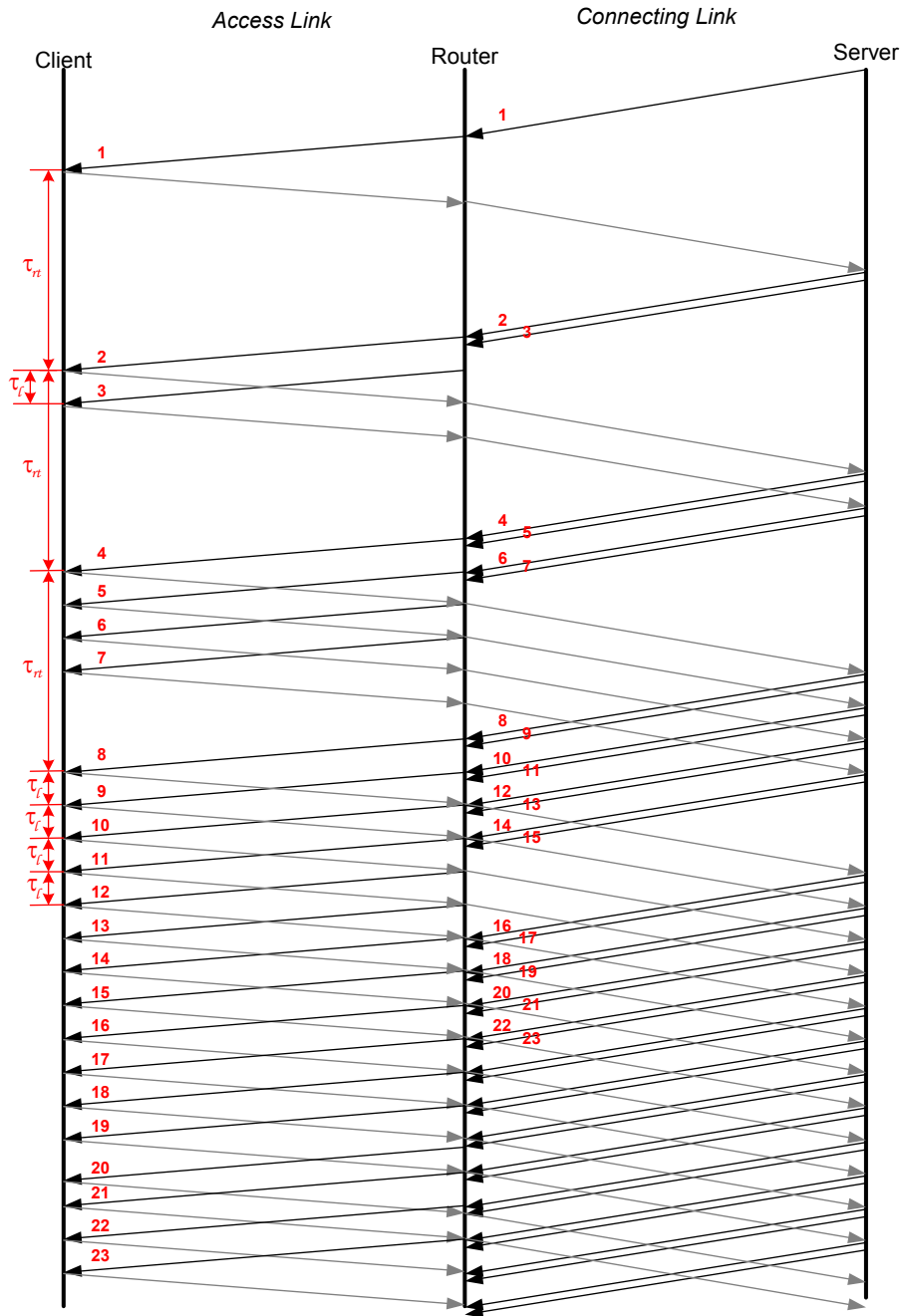


Figure 4 TCP Flow Control During Slow-Start; τ_t = Transmission Time over the DL; τ_{rt} = Roundtrip Time

Table 2 Delay components in the TCP model for the DL traffic

Delay component	Symbol	Value
The transmission time of a TCP data segment over the access link from the base station router to the client.	τ_4	Determined by the access link throughput
The sum of the time taken by a TCP ACK to travel from the base station router to the server and the time taken by TCP data packet to travel from the server to the base station router.	τ_5	See 4.5.1
The time taken by a TCP data segment to travel from the base station router to the client.	τ_6	See 4.5.1

From Figure 3 and Figure 4, it can be observed that, during the slow-start process, for every ACK packet received by the sender two data segments are generated and sent back to back. Thus, at the mobile station (base station), after a packet is successfully transmitted, two segments arrive back-to-back after an interval $\tau_u = \tau_2 + \tau_3$ ($\tau_d = \tau_5 + \tau_6$). Based on this observation, the packet arrival process at the mobile station for the upload of a file is shown in Figure 5. It is described as follows:

1. Let S = size of the file in bytes. Compute the number of packets in the file, $N = \lceil S/(MTU-40) \rceil$. Let W = size of the initial congestion window of TCP. The MTU size is fixed at 1500 bytes
2. If $N > W$, then W packets are put into the queue for transmission; otherwise, all packets of the file are put into the queue for transmission in FIFO order. Let P = the number of packets remaining to be transmitted beside the W packets in the window. If $P = 0$, go to step 6
3. Wait until a packet of the file in the queue is transmitted over the access link
4. Schedule arrival of next two packets (or the last packet if $P = 1$) of the file after the packet is successfully ACKed. If $P = 1$, then $P = 0$, else $P = P - 2$
5. If $P > 0$ go to step 3
6. End.

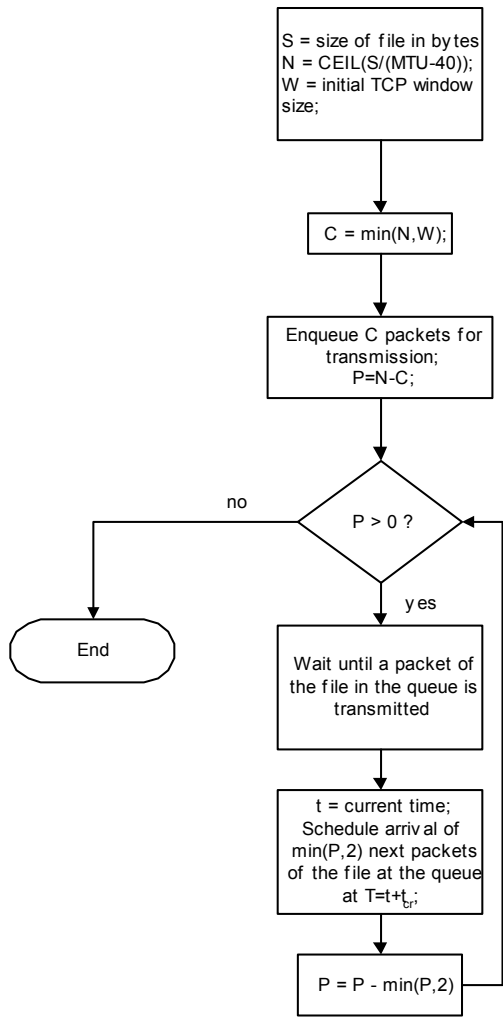


Figure 5 Packet Arrival Process at the mobile station (base station) for the upload (download) of a File Using TCP

4.5 Backhaul Network Modeling

4.5.1 Network Delay model

The one-way Internet packet delay is modeled using a shifted Gamma distribution [6-] with the parameters shown in Table 3. The packet delay is independent from packet to packet.

Table 3 Parameters for the shifted Gamma Distribution

Scale parameter (α)	1
Shape parameter (β)	2.5
Probability density function (PDF)	$f(x) = \frac{(x/\alpha)^{\beta-1} e^{-x/\alpha}}{\alpha \cdot \Gamma(\beta)}$ <p>$\Gamma(.)$ is the gamma function</p>
Mean	$\alpha\beta$
Variance	$\alpha^2\beta$
Shift	See Table 4

Two values, 7.5ms and 107.5ms are used for the shift parameter in order to model the domestic routes and the International routes respectively. The users' routes are selected randomly at the time of drop with the distribution shown in Table 4.

Table 4 Shift parameter for the Domestic and International IP routes

IP Route Type	Percentage of users	Shift parameter	Mean one-way IP packet delay
Domestic	80%	7.5ms	10ms
International	20%	107.5ms	110ms

4.5.2 Network Loss model

The transmission of IP packets between the base station (server) and the server (base station) is assumed error free.

Table 5 Internet Loss Model

IP packet error rate	0% (lossless packet transmission)
----------------------	-----------------------------------

4.6 Mobility Modeling

<For example, Handoff modeling>

4.7 Control signaling modeling

4.7.1 DL signaling models

<For example, models for MAC state transition messages and scheduling grant transmission etc.>

4.7.2 UL signaling models

<For example, models for access channel, ACK and channel quality Feedback etc.>

5 Channel Modeling

5.1 Channel Mix

<Percentage of different Channel types>

5.2 Channel Models

<Input from Traffic and Channel Models Correspondence Group>

6 Equipment Characteristics

6.1 Antenna Characteristics

<antenna pattern, number of antennas, antenna array geometry (if applicable), orientation, number of sectors>

6.2 Hardware Characteristics

The assumed hardware parameters of both the basestation and the user terminals are necessary to interpret the quoted results. For example, differences in specification (both BS and UT) significantly affect performance results:

- maximum output power
- noise figures
- antenna gain, pattern, and height
- cable loss (if applicable).

6.3 Deployment Characteristics

Relevant system-level parameters used for an 802.20 deployment include:

- number of carriers
- total spectral bandwidth
- system frequency allocation
- sectorization (if applicable)

7 Output Metrics

<For example, spectral efficiency, number of users supported per sector, per user throughput and system capacity etc.>

Two good criteria for evaluating the network-level performance of an MBWA system are its ability to cover the worst served users and the aggregate throughput that can be delivered within the cell. In this section, statistics for quantifying these aspects of network-level performance are described.

7.1 System Capacity Metrics

This section presents several metrics for evaluating system capacity. Specifically, respondents are required to provide:

- User data rate CDF for specified load and basestation separation (Section 7.1.1: Fixed load/coverage operating point: Service Distribution)
- Plot of aggregate throughput vs. basestation separation for stated minimum service levels. (Section 7.1.2: Aggregate Throughput)
- Plot of number of active users per cell vs. basestation separation for stated minimum service levels (Section 7.1.3: Network performance under Varying Load/Coverage)
- Spectral Efficiency for stated load coverage operating points (Section 7.1.4: Computing Sustained Spectral Efficiency)

The results presented for the uplink and downlink capacity should be achievable simultaneously by the system. If the results for uplink and downlink cannot be achieved simultaneously by the system, the respondent should indicate so.

7.1.1 Fixed load/coverage operating point: Service Distribution

Let the load/coverage point be *fixed* at (N_u, S) , where (by definition) the number of active users per cell² (N_u), and the (common) inter-basestation separation (S) for a hexagonal tessellation of N_c cells is specified. This operating point implies a distribution $D(N_u, S)$ of data rates for each user that the system is able to deliver within the cell area. We propose that the distribution $D(N_u, S)$ be sampled separately in uplink and downlink directions (Monte-Carlo simulation) with statistics gathered only from the interior cells of the network.

² See Section 10.1 for definition of active users

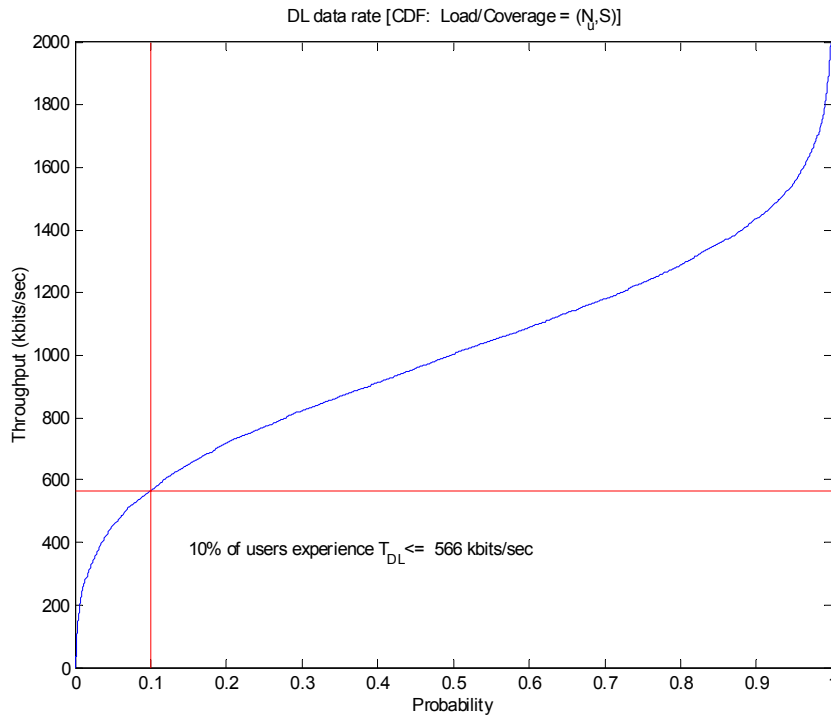


Figure 6: Service Distribution for a fixed load/coverage operating point

Figure 6 shows a qualitative example of a cumulative distribution function (CDF) of the distribution of downlink data rates $D(N_u, S)$ in the interior cells of a network for a specified load/coverage operating point (N_u, S) . This graph shows the distribution of data rates on the *ensemble* of random placements of N_u active users in each cell of the network and all other stochastic input parameters. The CDF is not complete without specification of the assumed probability distribution of user placement.

7.1.1.1 Minimum Service Level

From a service integrity standpoint, the lower tail of the resulting service CDF contains important information. Continuing the example of Figure 6, 90% of the active users will be served with a *minimum service level* of 566 kbits/sec at the load/coverage operating point (N_u, S) . The notation $T_{DL}(N_u, S)$ emphasizes that the minimum service level is a function of the load/coverage operating point.

7.1.2 Aggregate Throughput

For each placement of users, the *aggregate throughput* is the sum of the data rates delivered to the N_u active users in a cell. The per-user *data rate* is computed by dividing the total number of information bits received by the time-duration of the simulation. The respondent should provide a graph of the aggregate throughput vs. basestation separation for constant minimum service levels (See Section: 7.1.3) . This graph would be of the same for as Figure 7 with the vertical axis being aggregate through put instead of number of users.

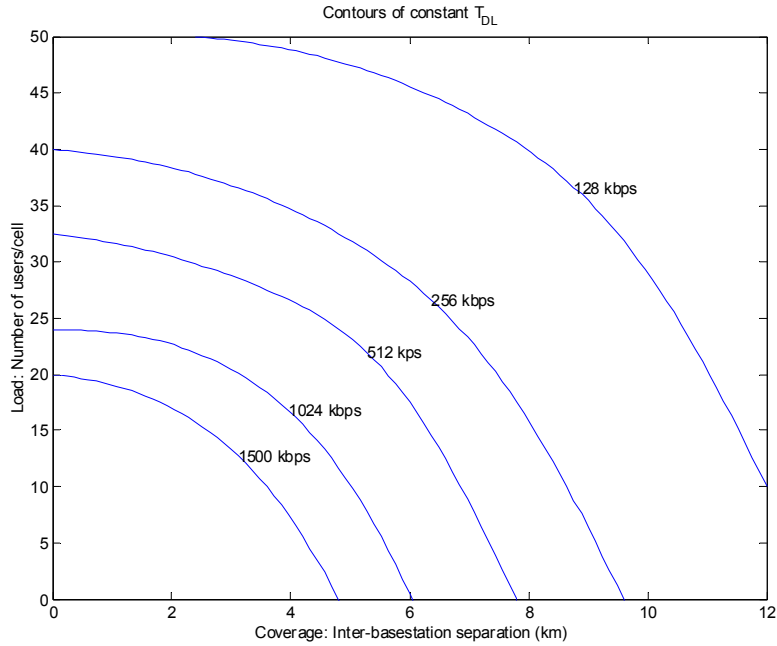


Figure 7: Contours of constant minimum service level

7.1.3 Network performance under Varying Load/Coverage

The CDF of Figure 6 characterizes the ability of the system to serve active users at a fixed load/coverage operating point. Studying the behavior of the system with varying network load gives additional insight. One interesting approach is to compute the minimum service level $T_{DL}(N_u, S)$ on a grid of points in the *load-coverage* (N_u, S) plane. Sample contours of constant minimum service level are shown in Figure 2. This example (synthetically produced for illustrative purposes), reveals the tradeoff between the basestation separation (S) and the number of active users per cell (N_u).

For example, to guarantee an expected minimum service rate of, say, 1024 kbits/sec across 90% of the cell area, few active users (less than 5) can be supported per cell at the noise-limited inter-basestation separation of 6 km. Conversely, many active users per cell (more than 20) can be supported in the interference-limited case when the basestations are closely spaced.

7.1.4 Computing Sustained Spectral Efficiency

In the present setting, the *sustained spectral efficiency* (η) can be computed in a meaningful and straightforward manner. A moment's reflection will reveal that rather than being a single number, *spectral efficiency* is a family of numbers parameterized by the load/coverage operating point (Section 7.1.1) and the assumed minimum service level.

For a specified operating point (N_u, S) and a minimum service level, the *expected aggregate throughput* (A) is defined as the expected sum of the data rates delivered to the N_U active users in the cell. For example, in the downlink direction, the expected aggregate throughput (per-cell) is defined

$$A_{DL} = E \left[\sum_{k=1}^{N_u} R_{DL,k} \right]$$

where $R_{DL,k}$ is the downlink rate to the k^{th} user and $E[\cdot]$ is the statistical expectation. A similarly defined statistic A_{UL} applies in the uplink direction. The total expected aggregate throughput is the sum of uplink and downlink: $A_T = A_{UL} + A_{DL}$.

The *sustained (total) spectral efficiency* is computed

$$\eta_T = \frac{A_T}{BW_T} \text{ bits / sec / Hz / cell}$$

where BW_T is the total system bandwidth. Similarly, the spectral efficiency is computed in the uplink direction as

$$\eta_{UL} = \frac{A_{UL}}{BW_{UL}} \text{ bits / sec / Hz / cell}$$

where BW_{UL} is the (effective) bandwidth reserved for uplink traffic. The spectral efficiency in the downlink direction is similarly defined.

8 Payload Based Evaluation

The payload-based evaluation method for MAC-Modem-Coding capacity and delay performance assessment is described below.

8.1 Capacity performance evaluation criteria

In order to evaluate the different proposals capacity performance, it is useful to define evaluation scenarios. The evaluation parameters are:

- Channel spacing: 1.25MHz and 5MHz
- Modem rate (max rate & minimum coding, medium rate & medium coding, minimum rate & maximum coding);
- MAC frame duration: 5ms

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While it should be required that these parameters be provided by the respondent for their proposal, the specific values should not be specified in this document as they are design choices rather than evaluation metrics.

For capacity evaluation, the payloads associated with every type service are:

- 30 bytes for VoIP, G.729 codec, 30ms period
- 1518 bytes for long IP packets;
- 64 bytes for short IPv4 packets;
- 40 bytes for video-conference, 64kb/s (64kb/s*5ms/8 =40bytes)
- 240 bytes for video-conference, 384kb/s
- T.B.C. bytes for multi-media streaming.

The computation shall take into account the influence of the MAC overheads, MAC granularity, interleaver, coding block, etc.

In order to simplify the procedure, only one type of traffic is assumed for all the Base Station subscribers. For every type of traffic shall be calculated the subscriber number, separately for up-link and down-link

Comment: Page: 1
It is not clear specifically what is being proposed in this section. Please clarify. Should this be addressed in the traffic model correspondence group?

8.2 Payload transmission delay evaluation criteria

The delay is an important factor for real-time services.

The payload transmission delay shall be evaluated according to the same procedure and parameters, as specified for capacity evaluation. The computation shall take into account the influence of the MAC granularity, interleaver, coding block, etc.

The delay will be calculated between the moment in which the payload enters the MAC and the moment in which the payload exits the MAC, on the other side of the wireless link. The processing power of the implied devices will not be taken into account.

The calculation shall be done separately for up-link and down-link, assuming the number of subscribers resulted from capacity calculation.

9 Fairness Criteria

In the evaluation of spectral efficiency and in order to make a fair comparison of different proposals, it is important that all mobile users be provided with a minimal level of throughput. The fairness is evaluated by determining the normalized cumulative distribution function (CDF) of the user throughput, which meets a predetermined function.

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

$$\tilde{T}_{put}[k] = \frac{T_{put}[k]}{\text{avg}_i T_{put}[i]}$$

The CDFs of the normalized throughputs with respect to the average user throughput within that traffic class is determined. Note that there are as many CDFs as the traffic types simulated simultaneously. The CDFs shall lie to the right of the curve given by the points in Table 6.

Table 6 Fairness Criterion CDF

<u>Normalized Throughput w.r.t average user throughput</u>	<u>CDF</u>
<u>0.2</u>	<u>0.0</u>
<u>0.3</u>	<u>0.1</u>
<u>0.4</u>	<u>0.2</u>
<u>0.5</u>	<u>0.3</u>
<u>0.6</u>	<u>0.4</u>
<u>0.7</u>	<u>0.5</u>

The users with normalized throughput below 0.2 are declared in outage. The percentage of users in outage shall be below 2%.

An example of normalized user throughput CDF is given in Figure 8. In this example plot, average user throughput is uniformly distributed between 20-100 Kb/s i.e. a factor of 5 difference between the best user and the worse user average throughput. It can be noted that this example CDF lies to the right of the fairness curve and hence meets the fairness criteria.

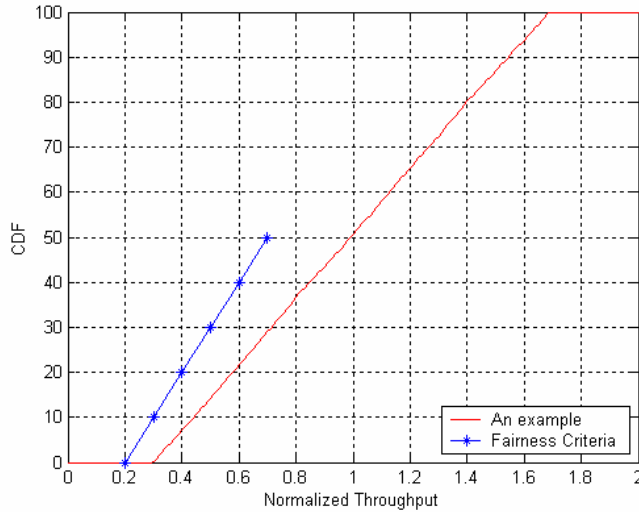


Figure 8 An example of normalized user throughput CDF.

Deleted: <Define fairness criteria that, for example, guarantee some minimal throughput to all users in the system>

10 Appendix A: Definition of terms

10.1 Number of Active Users Per Cell

For the purposes of this analysis, an *active user* is a terminal that is registered with a cell and is seeking to use air link resources to receive and/or transmit data within the simulation interval. Evaluating service quality as a function of the well-defined concept of the number of active users per cell is a natural way of comparing how well disparate MBWA systems behave under increasing network load.

10.2 Inter-basestation separation

For the purposes of defining network load, it is natural to treat inter-basestation distance as a parameter. Closely spaced deployments will stress the interference-limited performance of the network while widely spaced deployments will stress the range-limited performance. In any case, users of an 802.20 system will likely experience different link quality at locations throughout the cell that depend both on the distance from the basestation and the inter-basestation separation. Thus, we include inter-basestation separation in our definition of the load/coverage operating point.

10.3 One-Way Internet packet delay

One-way Internet packet delay is defined as the time it takes for an IP packet to travel from the base station (server) to the server (base station).

11 References

- 1- IEEE C802.20-03/32, Selected Topics on Mobile System Requirements and Evaluation Criteria.
- 2- IEEE C802.20-03/33r1, Criteria for Network Capacity.
- 3- IEEE C802.20-03/35, Evaluation Methodology for 802.20 MBWA.
- 4- IEEE C802.20-03/43, 802.20 Evaluation Methodology Strawman - 00.
- 5- 3GPP2/TSG-C.R1002, "1xEV-DV Evaluation Methodology (V14)", June 2003.
- 6- A Corlett, D.I. Pullin and S. Sargood, "Statistics of One-Way Internet Packet Delays," *53rd IETF*, Minneapolis, March 2002.

Appendix A: 19 Cell Wrap-Around Implementation

The cell layout is wrap-around to form a toroidal surface to enable faster simulation run times [5-]. A toroidal surface is chosen because it can be easily formed from a rhombus by joining the opposing edges. To illustrate the cyclic nature of the wrap-around cell structure, this set of 19 cells is repeated 8 times at rhombus lattice vertices as shown in Figure 9³. Note that the original cell set remains in the center while the 8 sets evenly surround this center set. From the figure, it is clear that by first cutting along the blue lines to obtain a rhombus and then joining the opposing edges of the rhombus can form a toroid. Furthermore, since the toroid is a continuous surface, there are an infinite number of rhombus lattice vertices but only a select few have been shown to illustrate the cyclic nature.

³ Note that the set of 19 cells are only repeated for illustrating the cyclic nature of the wrap-around cell structure. The simulation only contains 19 cells and not 9 sets of 19 cells.

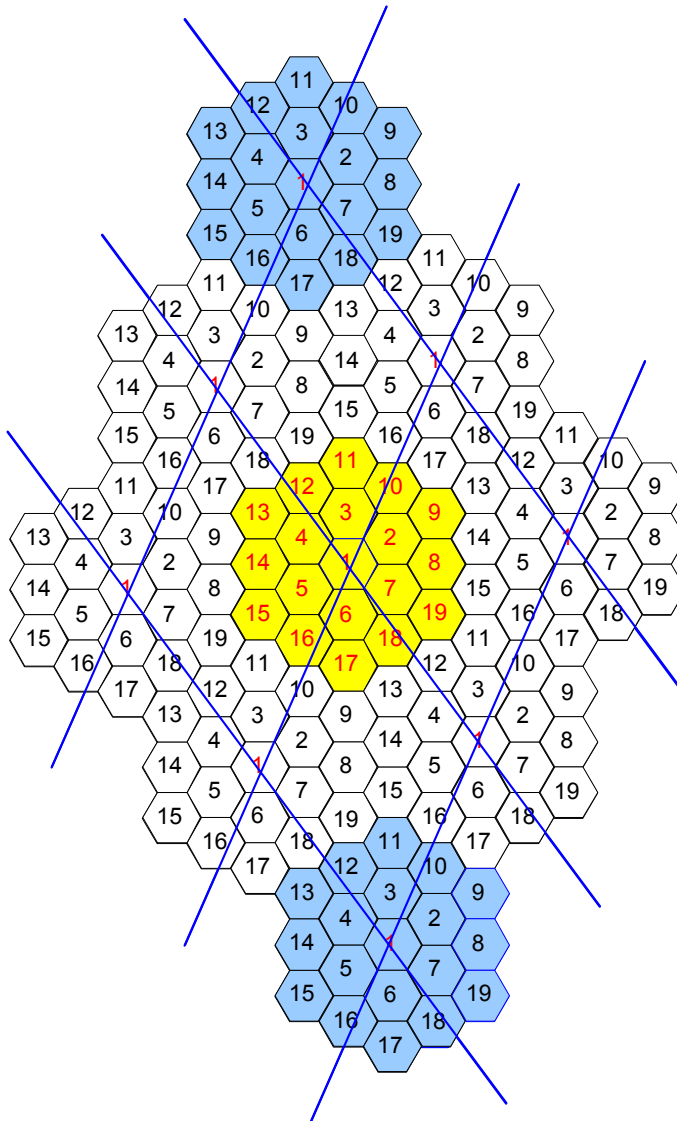


Figure 9 Wrap-around with '9' sets of 19 cells showing the toroidal nature of the wrap-around surface.

An example of the antenna orientations in case of a sectorized system is defined in Figure 10. For simplicity, the clusters in blue from Figure 9 have been deleted in this Figure. The distance from any MS to any base station can be obtained from the following algorithm: Define a coordinate system such that the center of cell 1 is at (0,0). The path distance and angle used to compute the path loss and antenna gain of a MS at (x,y) to a BS at (a,b) is the minimum of the following:

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

- b. Distance between (x,y) and $(a + 3R, b + 8\sqrt{3}R/2)$;
- c. Distance between (x,y) and $(a - 3R, b - 8\sqrt{3}R/2)$;
- d. Distance between (x,y) and $(a + 4.5R, b - 7\sqrt{3}R/2)$;
- e. Distance between (x,y) and $(a - 4.5R, b + 7\sqrt{3}R/2)$;
- f. Distance between (x,y) and $(a + 7.5R, b + \sqrt{3}R/2)$;
- g. Distance between (x,y) and $(a - 7.5R, b - \sqrt{3}R/2)$,

where R is the radius of a circle which connects the six vertices of the hexagon.

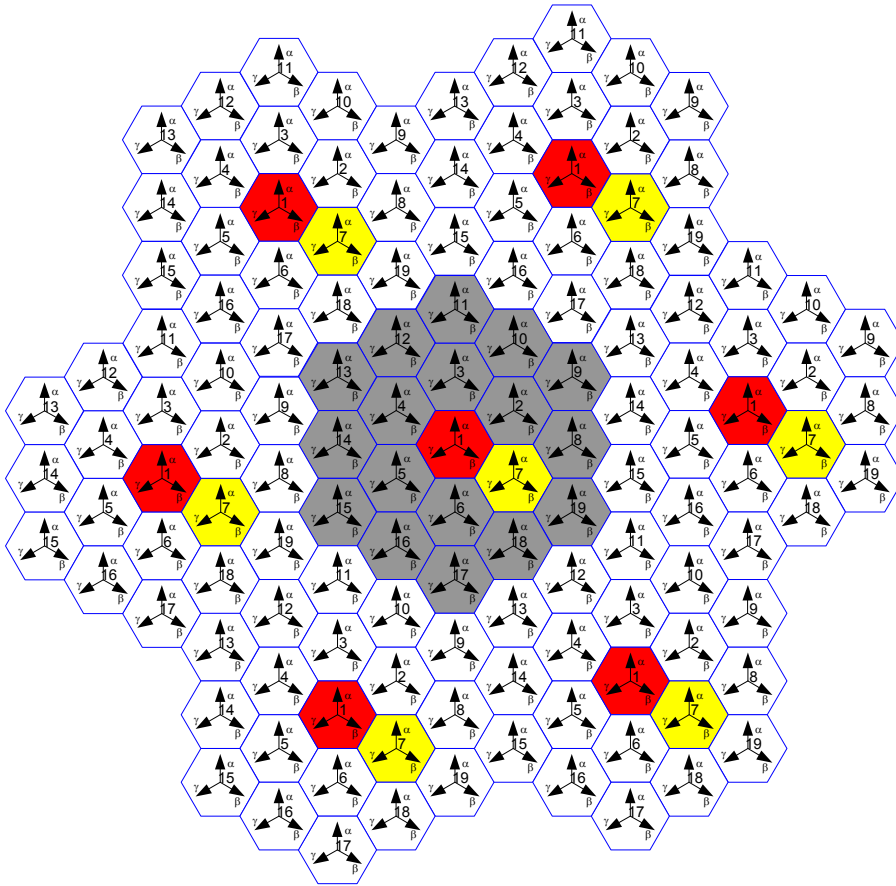


Figure 10: An example of the antenna orientations for a sectorized system to be used in the wrap-around simulation. The arrows in the Figure show the directions that the antennas are pointing.