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Re:	This contribution is submitted in response to the Call for Contributions from the chair of 802.20 for its May 2003 meeting.	
Abstract	A criteria for quoting network-level performance is proposed.	
Purpose	For informational purposes only.	
Notice		
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Patent Policy		

Criteria for Network Capacity

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1 Introduction

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, 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 network-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.

This contribution proposes that an appropriate way to gain insight into a system's network-level performance is to study its performance as a function of the **load/coverage operating point**, defined as the combination of both the network load (number of active users per cell) and the inter-basestation separation.

This contribution further proposes that an appropriate way to quote system performance is to present the Monte-Carlo generated distribution of achievable user data rates for a specified load/coverage operating point. The achieved **service level** at the tail of this distribution and the aggregate **spectral efficiency** can be used to characterize performance for the purposes of evaluation. We define each of these quantities in this contribution.

2 Performance of MBWA Systems

2.1 Link-level Performance

We define *single user link-level* analysis as 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, 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 extrapolated to network-level performance.

2.2 Network-level performance

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 network-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, network-level performance quantifies what is likely.

3 Parameterization of MBWA Networks

Having established the importance of evaluating performance in the context of a loaded network, organizing the many variables, assumptions, and defining a meaningful output evaluation criteria is daunting.

We propose a simple approach: quote performance as a function of and for multiple values of a **load/coverage operating point**. This parameterization defines the "loading" of the network with respect to the number of active users (defined below) served per cell and the inter-basestation separation (equivalently, the cell coverage). The combination of the number of active users per cell and the inter-basestation spacing is a load/coverage operating point.

In this section, we further define the load/coverage operating point and identify some of the other key simulation assumptions that can affect network-level performance significantly. We propose that the proponent of any system carefully quantify these assumptions (or others as appropriate for the particular air interface) with any reported simulation results. The subject of network-level performance metrics is addressed in the next section.

3.1 The Load/Coverage Operating Point

Here, the two variables comprising the load/coverage operating point are defined. This parameterization is convenient for assessing the viability of an 802.20 system as it clearly represents both the number of users supported by the network and the geographic coverage of the cell.

Input Variable 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.

Input Variable 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.

3.2 Input Assumptions

This section outlines the input assumptions that should be specified for evaluating the performance of 802.20 systems in a meaningful way. While these assumptions are important in determining system performance, they are often treated as fixed quantities in given deployment scenarios. For example, performance is often presented for rural, suburban, and urban rollout scenarios in which the input assumptions are set at well-documented values for each scenario.

3.2.1 The MBWA Network Topology

We recommend a simple hexagonal tessellation of cell sites. While this has the disadvantage of not modeling certain types of deployments (e.g., urban canyon), it is simple to simulate and can be made uniform across all the air interfaces.

To faithfully model inter-cell interference, we suggest that statistics be gathered only for cells that are *interior* to the network. Two possible scenarios are:

- Two tier: 19 basestations, statistics collected only from the interior cell
- Three tier: 37 basestations, statistics collected only from the interior 7 cells

This simple guideline protects the statistics from bias due to unrealistic performance around the edges of the network where inter-cell interference is artificially small due to the finite number of cells.

3.2.2 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).

3.2.3 Distribution of users

Most users of wireless systems experience very good link-quality near the basestation. 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.

3.2.4 System Parameters

Relevant system-level parameters include:

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

3.2.5 User usage model

The following user terminal usage parameters must be specified:

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

3.2.6 Propagation and Channel Model

Performance results cannot be interpreted without a detailed description of the channel model. It is particularly important that the pathloss and shadowing model be understood as these significantly affect the average signal quality. These include:

- pathloss model including pathloss exponents and corrections
- outdoor shadowing standard deviation
- indoor mean wall loss and standard deviation
- outdoor shadowing correlation between a user terminal and two separate base stations
- indoor penetration shadowing correlation between a user terminal and two separate base stations
- fast fading environment

4 The Outputs

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 delivered within the cell. In this section, we propose statistics for quantifying these aspects of network-level performance.

This contribution does not contain simulation results for any existing air interface. We supply synthetically generated data for the sole purpose of illustrating the utility of the proposed evaluation criteria.

4.1 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 cell (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.

Figure 1 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.

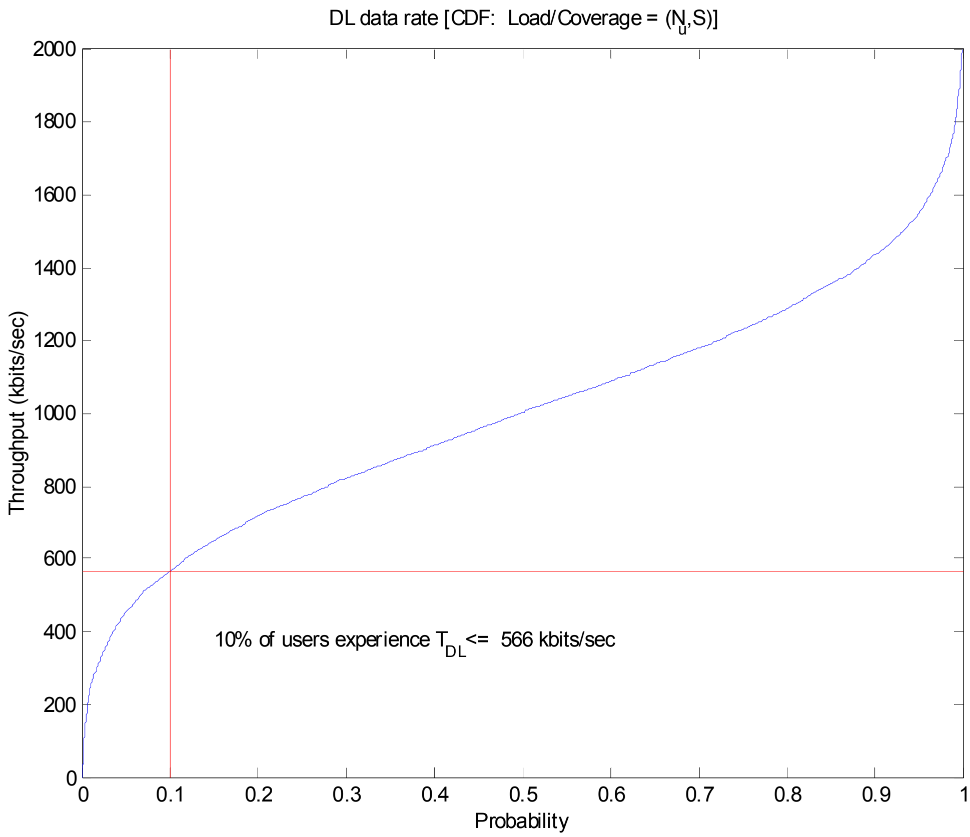

Figure 1: Service Distribution for a fixed load/coverage operating point

4.2 Minimum Service Level

From a service integrity standpoint, the lower tail of the resulting service CDF contains important information. Continuing the example of Figure 1, 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.

4.3 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.

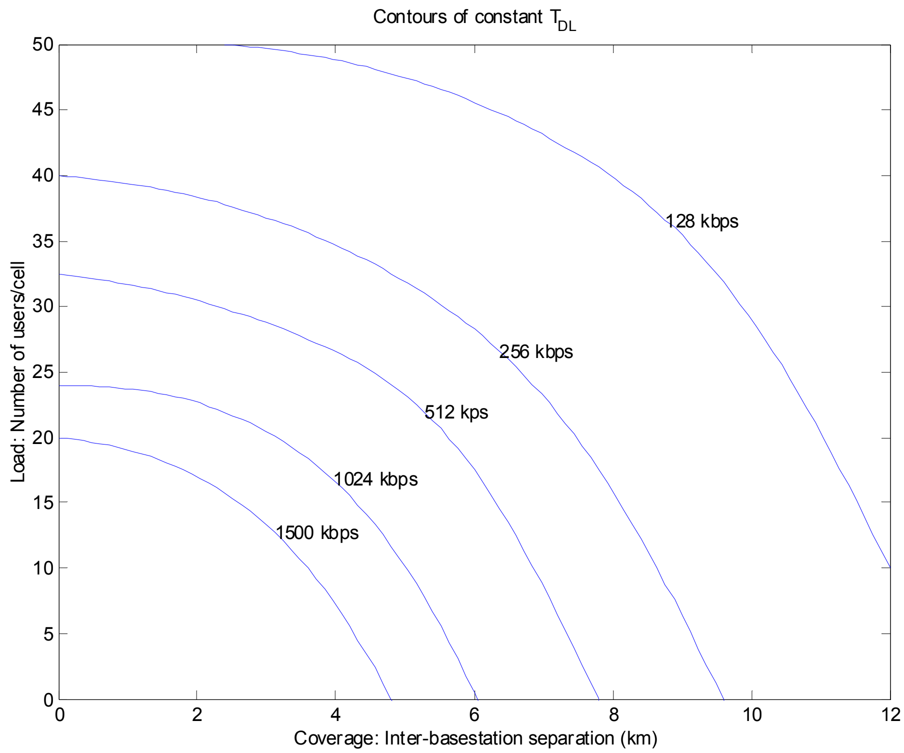

Figure 2: Contours of constant minimum service level

4.4 Network performance under Varying Load/Coverage

The CDF of Figure 1 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.

5 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 3.1) 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

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

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

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

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

6 Conclusion

In this contribution we have proposed that network-level performance as opposed to link-level performance be used to characterize the performance of 802.20 systems to address the issue of sustained spectral efficiency as emphasized in the PAR.

We stress that a single number cannot adequately represent performance. Rather, input assumptions, the load/coverage operating point, the minimum service level, and the spectral efficiency must be quoted together for a meaningful measure of performance.

The clearest representation of MBWA system performance and minimum service level is in terms of the cumulative distribution function of achieved data rates at a given load/coverage operating point.