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Coverage Evaluation Methodology for Next Generation Wireless Systems

Gamini Senarath, Shalini Periyalwar, Martin Smith and Robert Matyas

Wireless Technology Labs, Nortel Networks, Ottawa

***Abstract*— This paper presents coverage performance evaluation methodologies for future wireless multi-media systems. Emphasis is given to systems that use adaptive modulation and coding based shared channels. The limitations of current coverage metrics are outlined and extensions to the definition of coverage are proposed to address them. *The concepts of service coverage*, *viable service offering, and multi-user coverage* are introduced*.* Coverage definitions and evaluation methodologies for both delay tolerant services as well as delay sensitive services are discussed with examples.**

***Index Terms*—Next Generation Wireless Systems, ubiquitous coverage, system performance, Quality of Service.**

Introduction

ONE of the major challenges faced by the emerging broadband wireless systems is to provide ubiquitous coverage for a wide range of multimedia services that are expected to become popular among wireless users. Cellular system performance is affected by 'coverage holes' (in which all or some of the services cannot be obtained), due to natural or man-made obstructions or due to not taking adequate measures to address the degradation of signal level as a mobile moves away from the base. Current systems including 3G (e.g. 1xRTT) and 3G evolution (e.g. 1xEV-DV, HSPDA) are also affected by this phenomenon as high rate services such as streaming video require a higher C/I which can only be provided in a limited area of the cell. While there are several promising techniques that have been considered to improve coverage, ranging from conventional techniques of power control and soft handoff to more recent concepts such as interference avoidance, intelligent beaming and relaying [3]-[5], a comprehensive coverage evaluation methodology to cater to the diverse needs of multimedia services has not been addressed in the literature,. A standard mechanism to measure coverage performance from an end user perspective is required, particularly for new systems employing variable rate shared channels with Adaptive Modulation and Coding (AMC).

Coverage performance is useful to system designers for initial assessment of the capability of a system or a technology, and for comparison with other systems. For the operators, coverage performance would need to indicate how well a system could support a given service. Therefore, it is important that coverage metrics reflect the end user performance of a system for a variety of services that the operator intends to support and that the performance be obtained without the need for complex end-to-end simulations.

The main objectives of this paper are to: (1) articulate how conventional metrics are inadequate to measure the coverage of next generation systems; and (2) propose extensions to the coverage definition and an associated evaluation methodology, to address the inadequacy. The proposed coverage definition and evaluation methodology can be used to compare different wireless access technologies or networks in terms of their ability to support different services.

This paper is organized as follows. The next section discusses the general definition of coverage and the impact of coverage on end user performance for different mobility situations. Following this, conventional coverage definitions are summarized, their inadequacy for use in future systems is highlighted, and .the required extensions to the coverage definitions are introduced and explained. The concepts of 'Service Coverage' and 'Viable Service Offering', as well as 'Single-user Coverage' and 'Multi-user Coverage' are described. The next section then applies the proposed coverage extensions, defines the coverage evaluation methodology for systems with dedicated channels as well as for systems with shared channels, and illustrates the use of the proposed coverage mechanisms with some examples.

Coverage, Mobility and End User Performance

In general terms, "coverage" can be defined as a measure of the system's capability to offer a given service with a defined bound on 'outage'. Outage occurs when a system cannot provide sufficient resources to support a given service, e.g., due to a radio link's C/I deteriorating to a lower level than that required by a voice service, or the packet loss is greater than some predefined level, for a given service. Outage is influenced by area coverage. The impact of area coverage on outage depends on the mobile speed and the service's delay bound.

Area coverage deficiencies impact initial session blocking in the case of stationary users, while it can impact both initial session blocking as well as outage in the case of mobile users. For stationary users located outside a coverage hole, a session is usually admitted to the system (under the assumption that no other user is competing for resources) since the signal quality is sufficient for a given service. The system can then sustain the service with no outage. For example, if a particular service has 99% area coverage the impact on end user performance is that the system will have 1% blocking.

For high-speed mobiles, initiation of a call in a poor coverage area may result in blocking. Further, with an admitted call, a mobile may experience outage if it cannot quickly go through a coverage hole. The speed determines the duration for which a mobile stays in a coverage hole. If the delay requirement (packet delay bound) is sufficiently large and the total area of coverage holes in a cell is small (e.g. < 1%), no packets will be lost. For medium speed mobiles however, there is a higher probability that it would take longer to cross a coverage hole resulting in more lost packets.

The exact requirement on area coverage to meet all the mobility situations and service delay bounds needs further investigation. For some of the evaluations in this paper, we assume that 99% area coverage is sufficient to limit per user service outage for all the mobility situations and delay bounds.

Need for New Coverage Metrics

Conventional Coverage Metrics

The primary service supported by 1G/2G systems is voice. These systems are traditionally circuit switched systems offering a dedicated channel to the admitted user. The loss of communication on this dedicated channel occurs primarily due to the received signal strength (RSS) or C/I falling below a threshold value. Therefore, coverage for 1G/2G systems is simply defined as a signal strength or C/I availability over the area. For example, in [2], coverage is defined as the percentage area over which a minimum specified signal level is available for reception for at least a specified percent of time; e.g. RSS > -80 dBm for 99% of the area for 99% of the time. For most systems, time variation was considered less significant than location variability with the measurement interval changed to 100 % of the time [2].

In 3G systems, the C/I or data rate distribution over the cell area has been used to reflect coverage. The underlying assumption is that a dedicated channel can provide the required rate as long as a specified C/I level can be maintained for that channel. In shared channel 3GEV systems, the data rate distribution is also used as a coverage measure. The next section discusses why the current coverage definitions are inadequate and proposes extensions to the existing coverage metrics.

Inadequacy of Conventional Metrics and Proposed Extensions

There are several reasons why the current coverage definitions are inadequate for 3G and next generation systems. First, the coverage depends on the QoS requirements of a service and needs to be evaluated for multitude of services. Second, some future systems such as the downlink of 1xEV-DV and HSPDA systems, and the uplink and the downlink of OFDMA system proposed for 802.16e use AMC based shared channels which needs special considerations when coverage is evaluated. These reasons are discussed in detail below.

1) **The coverage for a given service depends on the QoS requirements of its data flows.** It is self-evident that the coverage for a delay sensitive, high rate, live video service is not the same as that for a delay tolerant low rate web browsing service. In addition, services with the same rate requirement but different delay and or outage requirements have different coverage levels. In this paper, we introduce the concept of *'**service coverage**'* – coverage defined as a service dependent attribute, to address this issue. Further, future systems should be able to sustain new services for which the QoS requirements are not known today. We address this with **a *generic service requirement*** *definition.*

2) **In systems using AMC based shared channels, multiple users access the channel at any given time**. When a shared channel is used in a TDM manner among users, the maximum rate for the channel is available only during the limited time for which the shared channel is scheduled for that user. Therefore, in a multi-user scenario the actual user throughput is only a fraction of the rate available to the user by the channel. We use a ***multi-user coverage metric*** to account for this behavior in shared channel systems.

3) The data rate of a shared channel does not indicate whether a system could offer to its customers as a ***'viable service offering'*** with the required availability and quality. For this purpose, the system should be able to support at least a certain minimum number of users simultaneously in a sector/cell. Thus, for a shared channel, the widely used coverage metric, "the percentage area where a given rate is available" would not provide sufficient information of a system's capability of a 'Viable Service Offering". For example, if a user can receive a 384 kbps data rate in a shared channel and the user wants to download a 384 kbps stream video session for two hours, this shared channel will be fully occupied by this user for the entire two-hour period. This is not a viable service as it would preclude other subscribers from having service during that time. We address this by including a requirement for coverage definition that a minimum number of users should be supported by a cell/sector, in order to be considered as providing adequate coverage for a given service.

4) In AMC based shared channels, the data rate available to a user varies with time due to fast fading and mobility. Since the rate variations of two users are usually not correlated, there is the opportunity to use the highest rate supportable on the link for a shorter period of time for a given user as done by some of the proposed schedulers[6], so as to maximize the system's aggregate throughput. This form of shared channel usage does not match with conventional rate coverage, which is more appropriate where the user's average rate would be based on the user accessing the channel over the whole time period of interest.

Coverage should then be assessed based on the proportion of time provided to the users and the highest rate available to a user during that time. We introduce new metrics called the Max User Average Rate (MUAR) and Maximum Service Rate (MSR) to address this issue in shared channel systems, which are discussed in detail later in this document.

5) Current 3G standards have not explicitly defined a coverage evaluation methodology. The 1XEV standard defines an overall system performance evaluation methodology [1] which requires exhaustive and time consuming end-to-end system level performance evaluations in order to determine the system's capability of supporting a given service. In this paper, we propose a simple methodology through which the proposed coverage metrics could be evaluated without resorting to detailed traffic modeling for each service offering. Using the generic service requirements definition, we

enable a simpler approach to assess coverage for a range of services.

Proposed Extensions to Coverage Definitions - Details

The proposed new considerations mentioned in the previous sections are described in detail below.

A. Service Coverage

As mentioned before the coverage is defined as a service dependent attribute since coverage depends on the QoS requirements of a service. For this purpose a generic service requirement definition is provided together with a service parameter based coverage evaluation methodology as explained below.

Service/Application Requirements: The QoS requirements of a service or a flow can be specified using packet delay, jitter and data rate. The jitter is addressed by having an adequate jitter buffer and can be included as an additional delay requirement. We propose that, for the purpose of coverage evaluation, these requirements be mapped to the following three link layer related requirements. Note that this is an approximate representation, which corresponds to the end user service requirements in the 1xEVDV methodology [1] in order to establish a simplified coverage evaluation methodology.

A service is characterized by:

- **A minimum required rate, Rmin** [1]
- **A delay requirement** represented by an observation window, ***Tw***. (For each time window Tw, a data rate of at least *Rmin* should be available for satisfactory service. This is to closely map the worst case requirement that the largest data burst should be delivered within the delay bound in order not to have packet losses).
- **A per user outage requirement (x%):**
  - *Delay tolerant case:* Because there is no delay limit, it may be assumed that the outage can be kept at or below the specified bound by leveraging ARQ as long as physical layer Frame Error Rate (FER) is below an acceptable threshold, say 2%. In this case, the effective rate after ARQ is close to the average rate and the per user outage requirement can be reflected by a negligible adjustment in rate.
  - *Delay sensitive case: Window outage* may be defined as the percentage of observation windows that cannot provide the minimum required rate, Rmin . As per this representation, a service can be provided to a user satisfactorily, if the system can offer a rate higher than Rmin in (100-x)% of observations windows (window size = Tw).

Rmin, Tw and *x* depend[1] on (and can be derived from) the PLR, the delay requirement, maximum burst size and the IP traffic arrival pattern.

Parametric approach to coverage evaluation for a range of services: Defining coverage for every service type will require extensive analysis and simulation. Instead of evaluating performance for a specific service or a data flow, we propose that a system's coverage capability be obtained for a range of QoS requirements so that any emerging or new service could be mapped into these requirements. An approximate view of the system's capability to provide these services to its customers can therefore be obtained. This would be helpful to identify the design gaps in terms of providing some services in a system, or for comparing two systems in terms of their service coverage capabilities. Some example parameter ranges are provided in Table 1.

Table 1 Parameter ranges to represent a wide range of services

Tw (msec)	10, 20, 50, 100, 200, 500, 1000, 2000
x (%)	0.1%, 1%, 2%, 5%, 10%
Rmin (kbps)	9.6,19.2, 64, 76.8, 384, 768, 1992

Thus, "service coverage" will characterize a system's coverage capabilities for a range of services.

B. Single User and Multi-user Coverage

[1] Requires more research on how *Tw* and *Rmin* values should be selected for a given service.

Metrics

As discussed before, for systems based on variable rate shared channels, a considerably different set of coverage metrics are needed from those of dedicated channel systems. A number of variables impact 'service coverage' in such systems, ranging from the instantaneous rates available to a given user, scheduling, to fairness.

The main difference is that the coverage depends on the number of active sessions sharing the channel at a given time. Therefore, a multi-user coverage metric needs to be introduced. However, single-user coverage or the area coverage may also be useful in order to get a preliminary view of the system capability. We propose that both metrics be used, with the following definitions.

Single User Coverage: The 'Single User Coverage' metric, which is also known as the Rate Coverage Curve - reflects the availability of a data rate over a service area assuming resources are not shared with other users.

Single user coverage for a given service with service parameters of Rmin, Tw and x can be defined as the percentage area in which a user can obtain the service assuming all the resources are available to that user.

Multi-user Coverage: The Multi-user coverage indicates the actual coverage the system can provide to users when several users are sharing the channel.

Multi-user coverage is defined as the percentage area that a service can be provided if at least n_0 number of users is to be simultaneously supported (i.e. can provide a viable service offering as explained below).

Let, n = maximum number of users that can be supported at a given coverage level (y%) for a given service (i.e. for a given set of service parameters).

Then, the given service is adequately covered for the y% of area, if $n > n_0$.

Single user and multi-user coverage are discussed in detail later in this document.

C. Viable Service Offering

We propose that a service should be considered viable, only if the service could be supported in y% of the area with at least n_o number of users in a sector obtaining the service simultaneously. Here, y and n_o are service dependent parameters decided by the operator according to the outage requirement of the service and operator's business strategy. For the evaluations in this document we use n_o= 10 (i.e. 10 users/sector or 30 users/cell) and y = 99. According to the proposed methodology, an operator can say, for example, that a 384 kbps streaming video service is a viable offering if that rate can be supported for at least 10 users/sector, with a 99% coverage.

Figure 1 shows viable services for an example system which we selected for evaluation. This representative system uses a subset of 1xEV-DV features. Note that this might not be representative of the actual performance of the complete 1xEV-DV system, rather, these results are used to show a representative system's ability to support different services.

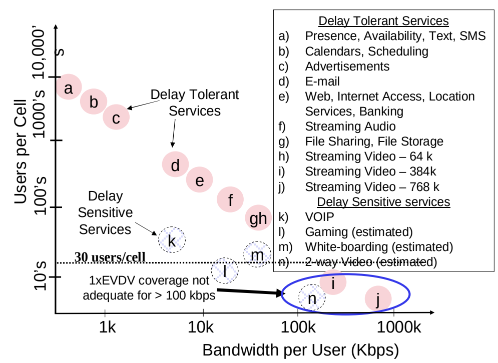

Figure 1 Services that can be supported with 99% coverage for an example 1xEV-DV system

As can be seen this type of diagram representing a plot of viable services for a system at a given coverage level will be very useful to get a good overall view of a system's capability. This will be helpful for the operators as well as for the system designers to identify the gaps in the system design or to compare systems.

It is important to note that all the delay tolerant service points are placed in an straight line when a logarithm scale is used and the delay sensitive points are placed below that line depending on the delay requirement.

For example, as can be seen in Figure 1, the representative system can support delay tolerant services up to 70 kbps for 99% coverage (with $n_0 = 10$) and services requiring higher data rates suffer from highly inadequate coverage. Using similar coverage evaluations, we have observed that the other shared channel based systems too suffer from coverage issues. Therefore, improving the coverage requires the special attention of the research community.

D. Max User Average Rate (MUAR) and Maximum Service Rate (MSR)

We introduce these metrics to address the aspects of rate variation and its exploitation by system schedulers in shared channel access. As can be seen in Figure 2, the system can select the user for transmission during its up fades (time slots T1, T2, T3 and T4) which will increase a user's average rate from User Average Rate (UAR) to Max User Average Rate (MUAR). Similarly for delay sensitive services, a Max Service Rate (MSR) can be defined to represent the highest rate a user can obtain during the fraction of the time the channel is used by that user in a given time window.

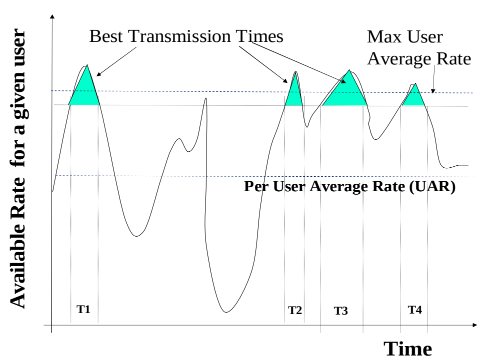

Figure 2 Fade Selective Transmission increases average data rate of a user under multi-user scenario

Proposed Coverage Definitions and Evaluation Methodology

In this section, we apply the proposed coverage extensions and provide example results. Since 3G, 3G evolutionary and future systems are expected to continue the use of power controlled dedicated channels even for data services, particularly for the uplink (e.g., 1xEV-DO), we briefly address service coverage for systems based on dedicated channels. Following this, shared channel based systems are examined in detail.

Service Coverage for Systems based on Dedicated Channels

A simple extension of a C/I-based coverage definition could be used for systems with dedicated, power-controlled (i.e. fixed-rate) channels (e.g., 1xRTT, UMTS). However, since services with different Quality of Service (QoS) criteria need to be supported, the coverage has to be specified separately for each service.

For a dedicated channel, the different QoS criteria (delay, jitter, required rate, burstiness) translate to different C/I limits and channel rates for each service to be rendered within the outage limits. For CDMA systems, higher rate service can be supported by the allocation of one or more dedicated CDMA Walsh channels (e.g. 1XRTT's allocation of fundamental + supplemental channels) to meet the required rate for that service. This rate may not be available for the entire cell due to a maximum power limitation for the set of channels used, thus limiting the coverage for higher rates.

Coverage Definition:

For a delay tolerant service, in order to satisfy the user requirements, the transmission rate of the dedicated channel should be equal to or larger than the average rate required for the service. Therefore, in this case the minimum required rate of the channel is the average rate of the service.

For a delay sensitive service, the required rate can be different from time to time depending on the bursts of data being received. So, in order to have no service disruption (e.g. no outage), the rate of the dedicated channel[2] should be larger than the worst case scenario, or Rmin (the rate required to transmit the maximum burst of data within its delay limit).

Therefore, for both cases of delay sensitive and delay tolerant services, the coverage

[2] Although it seems inefficient to allocate a dedicated channel in this way to handle the worst case scenario for bursty data, in practice, this allocation can be done dynamically, allocating and releasing the high rate channel as necessary.

requirement could be specified as a minimum rate requirement and coverage can be specified by the rate distribution.

Evaluation methodology and Example Evaluations: Coverage evaluation involves obtaining C/I distribution over the cell area and map the C/I availability as a rate availability. The coverage of a specified service could be obtained by mapping the service requirement as a rate requirement. Thus, coverage can be obtained for different services (i.e. cumulative rate distribution). The resulting coverage curves will be similar to that indicated in Figure 3 for shared channel systems and therefore we did not include results here. The viability of a service is to be determined by the capacity performance (the number of channels that can be supported), as capacity performance can be decoupled from the coverage performance for the case of dedicated channels.

Service Coverage for Systems with AMC based Shared Channels: Delay Tolerant Services

In this section, further details are provided on the single user and multi-user coverage metrics for shared channel systems. Each metric is described in three steps: the definition of the metric, evaluation methodology and example results or projected performance.

Single User Coverage

Definition: The single user coverage definition in the previous section can be used here. For delay tolerant services, Tw is very large. Although in theory, these curves need to be provided for different values of outage x, as discussed previously, the impact of x on coverage is negligible.

Evaluation Methodology: First the C/I profiles are obtained for a large number of uniformly distributed users in the area and evaluating the corresponding mean data rate for each user. The cumulative distribution of the data rate directly provides the area coverage values as per the above definition.

Example Evaluation: Figure 3 provides a single user coverage distribution for an example shared channel based OFDM system (Sys2) we used for our evaluations. Figure 3 also indicates how Soft Handoff (SHO) provides large rate coverage gains (2 to 4 times gain) although the results provided later with new metrics (Figure 5) will demonstrate that there is actually little improvement (20%) to the end user. This shows that the single user rate coverage does not provide the full coverage information of a system.

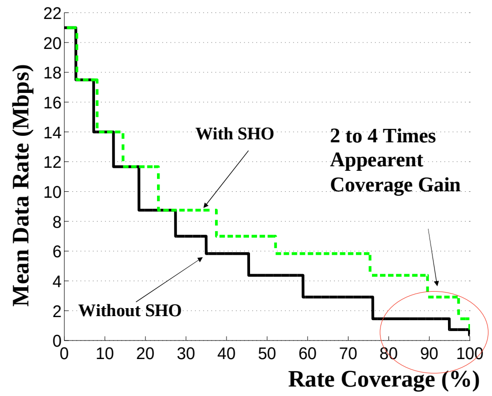

Figure 3 Rate coverage curves show large gains for SHO for an example OFDM system

Multi-User Coverage

As discussed before, multi-user coverage indicates the actual coverage the system can provide to users when several users are sharing the channel. For example, if the time slots are distributed equally among active users, the rate coverage curve with two users is approximately half that of the rate coverage with a single user (i.e. in Figure 3, for a given coverage level, the throughput a user actually receives will be half of the rate shown in the curve). Therefore, if equal time slot scheduling (ETS) is assumed, the rate coverage is 1/N of that of the single user coverage, if N is the number of users in the system.

However, equal time slot allocation results in unequal throughput among users and the resulting unfairness in throughput could be different from system to system (it depends on the rate distribution among users). Therefore, the coverage of two systems cannot be compared on the basis of ETS scheduling. In order to avoid this scheduling bias in coverage evaluation, we propose to use equal throughput (EQT) scheduling as the basis for coverage evaluation.

Definition: The multi-user coverage definition provided in the earlier section is to be used here (i.e. The percentage area a user can get a service if at least n_0 number of users is to be supported by the system)

Evaluation Methodology: It can be easily shown that the EQT scheme maximizes the number of users given a set of data rates, associate probabilities and the required minimum rate. The resulting number of users can be evaluated as shown below.

Let us assume, that the probability of transmitting at a rate, *R(i)* is *P(i)*, and that there are m such possible rates (i.e. in general, each rate group can have different number of users).

If the minimum average required rate for the service is *Rmin*, the fraction of the channel time used by a user form the ith group is *Rmin/R(I).* If the total number of users that can be supported is *Neqt*, the number of users using the rate *R(I) is Neqt* P(i).* For a single shared channel, these fractions should add to 1. Therefore,

$$\sum_{i=1}^{m}\left(Neqt * P(i) * \frac{R\min}{R(i)}\right) = 1$$

$$Neqt = \frac{1}{R\min \sum_{i=1}^{m} \frac{P(i)}{R(i)}}$$

Evaluation Methodology when mobiles use resources of multiple base stations: When some users use resources of more than one base station (for example when SHO is used), the above EQT equation should be modified to evaluate the number of users that can be supported. Depending on whether a mobile uses multiple link resources, another parameter, link(i) is introduced. link(i) represents the number of base stations a user has to be connected to (in the case of 2-way SHO link(i) = 2). The expressions are modified as follows.

$$\sum_{i=1}^{m}\left(Neqt * link(i) * P(i) * \frac{R\min}{R(i)}\right) = 1$$

$$Neqt = \frac{1}{R\min \sum_{i=1}^{m} \frac{P(i)}{link(i) * R(i)}}$$

Evaluation Examples: Figure 4 shows the results obtained for a representative system comprising a subset of 1xEVDV features, for delay tolerant services. Due to the assumptions made, the results should be viewed only as the coverage capability of a representative system and not that of a 1XEVDV system. The number of EQT users that can be supported is obtained from the above equation. As per the results, 70 kbps can be supported with a 99% coverage, if a minimum of 10 users are to be supported per sector.

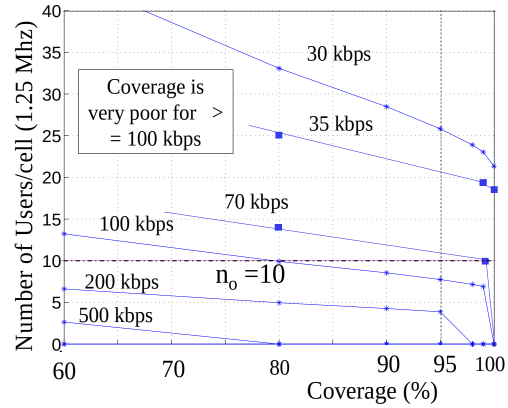

Figure 4 Delay Tolerant Service Coverage of a Representative 1xEV-DV System

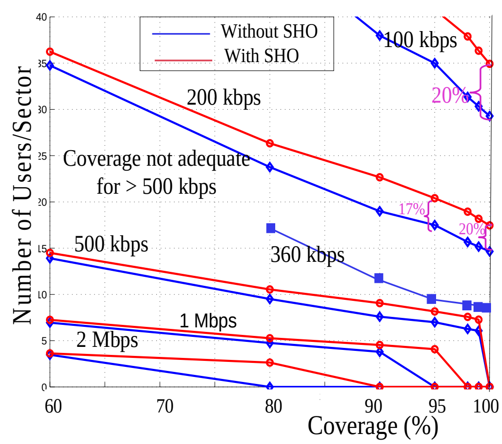

Figure 5 Delay tolerant Service Coverage of an Example OFDM System

Figure 5 shows similar results for an example OFDM downlink with an AMC based shared channel. As can be seen, up to 360 kbps service is viable with 95% coverage with a minimum of 10 users/sector supported by the system.

This means that a 20% coverage gain is

obtained using SHO according to the multi-user metric. As the actual end-user capability should be measured by the number of users the system can be supported this indicates the true impact of SHO on the end user performance although the single user coverage metric shows more than 100% improvement. Therefore, we can conclude that the new multi-user coverage metric reflects the true coverage capability of a system.

EQT scheduling which maximizes the number of users in the system provides a reliable means of comparing two systems, because the use of different schedulers can change the fairness of a system. When two systems are compared that should be done under same fairness situations. However, equal time slot scheduling and proportional fair scheduling gives rise to unequal throughputs for different users, the distribution of which depends on the type of scheduler. It should be noted that when such a scheduler is used, the resulting fairness can be different from system to system and the comparison of the throughput or capacity is not accurate. Therefore, the EQT coverage numbers provide a reliable method of comparing two systems through which the systems 'built-in' capability is measured as opposed to measuring the 'scheduler dependent' capability.

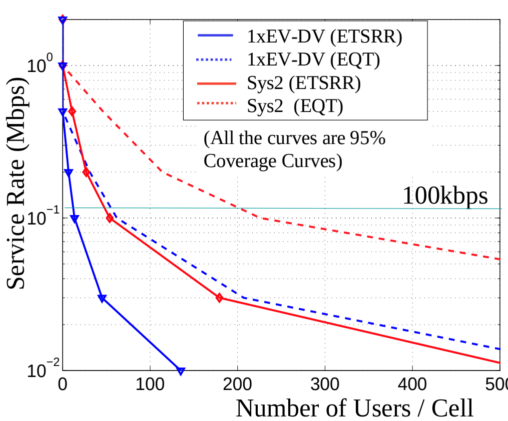

Figure 6 Coverage under EQT and ETSRR scheduling for two different systems.

In order to illustrate these facts, we have evaluated the service coverage of the example 1xEVDV system and another AMC based system (Sys2) with EQT scheduling as well as Equal Time Slot Round Robin (ETSRR) scheduling in Figure 6. As can be seen, if the comparison is done without considering the scheduling, an inaccurate assessment could have been made. For example, the coverage with EQT for 1xEVDV is better than the Sys2 under ETSRR scheduling although Sys2 has superior performance, when the two are compared under similar conditions.

The evaluation of system coverage under fade selective scheduling schemes such as Proportional Fairness [6] is difficult as the channel rate maximizations can happen in multiple users in the same time. An approximate coverage value can however be obtained by using the new metrics, MSR and MUSR (defined before) when evaluating multi-user coverage. In that case, underlying assumption is that there are large number of users so that the system can always find a near optimum mobile for a particular time slot. The extension of the proposed evaluation methodology to other scheduling schemes requires further investigation.

Service Coverage for Systems with AMC based Shared Channels: Delay Sensitive Services

Similar to the delay tolerant case, we discuss single user coverage and multi-user coverage in two separate sections.

Single User Coverage

Definition: This is defined similar to the previous single-user coverage, as rate distribution is provided against the corresponding coverage However, in order to cover the full range of services (i.e. for different delays, different outage values), several rate curves are needed.

Evaluation Methodology: First, a number of mobiles (n) are dropped uniformly in the area of interest. For each user, the Average Window Rate (AWR) is evaluated for a large number of non-overlapping time windows. The cumulative distribution of AWR is obtained for different delay values. Whether a given service can be supported by a given user can be found out by these distributions (see Figure 7). By obtaining these details for all the users, the percentage of users in outage can be obtained for a range of parameters, which can be plotted as in the example shown in Figure 8.

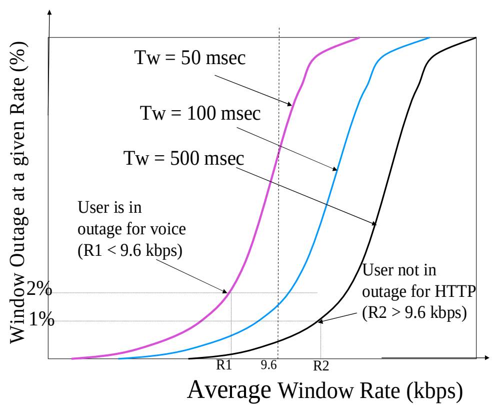

Figure 7 Window outage at different data rates for an example user

Example Evaluation: Figure 7 illustrates a per window data rate distribution that can be obtained for a given user. This example user cannot support a service with Tw = 50 msec, Rmin = 9.6 kbps and x = 2% (e.g. voice). In other words, a service with a delay requirement of 50 msec can be supported only if Rmin is less than R1. The user can also support a service with Tw = 500 msec, Rmin = 9.6 kbps and x = 2% (e.g. HTTP).

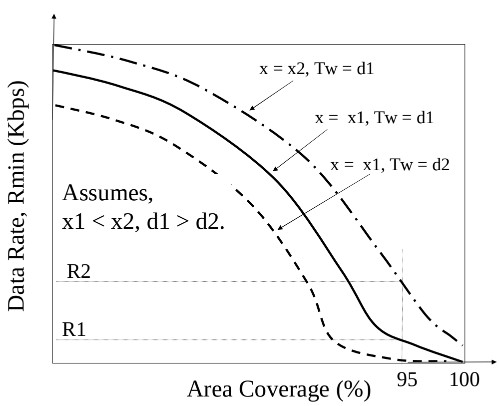

Figure 8 An Illustration of Single User Coverage Curves for Delay Sensitive Services

By obtaining these details for all the users, the percentage of users in outage can be obtained for a range of parameters which can be plotted as in Figure 8 to provide full coverage picture for the delay sensitive services under the single user assumption (as discussed before, the multi-user coverage is much less than that indicated by this curve).

As per the illustration, a service with Rmin < R2, Tw = d1 and x = x2 has a single user coverage > 95%. With Tw = d1 and x = x1 (x1 < x2) the 95% coverage is R1 (< R2). By obtaining these curves for a range of parameters, the coverage for a particular service can be obtained by mapping its parameters to the appropriate point in these curves.

Multi-user Coverage

Definition: The definition of Multi-user coverage is similar to the delay tolerant case although the service requirement now includes a time window to represent the delay bound effect. The coverage is defined as the percentage area that a service can be provided if at least n_0 number of users is to be supported (i.e. can provide a viable service offering).

Evaluation Methodology: First, a number of mobiles (N) are dropped uniformly in the area of interest. The data rate of each user is obtained for a large number of non-overlapping time windows. For each time window, the number of users that can be supported is obtained by selecting mobiles one by one evaluating the fraction of time the user required to receive *Rmin*Tw* bits[3], for that window until the window time is fully used. Alternatively, the number of users can also be evaluated using the EQT expression provided earlier once the available rates for each mobile in each slot are known.

The cumulative distribution of the number of users obtained in this manner for a large number of windows is then plotted. The yth percentile value of number of users indicates the number of users that can be supported by the system with *(100-y)%* coverage. These curves are then repeated for a range of *x* (per user window outage) and window sizes (*Tw*) as mentioned before.

Example Evaluation: A representative curves that can be obtained from such an evaluation are shown in Figure 9. It shows curves correspond to 99% coverage. The top curve is the 99% service coverage curve

[3] This is the minimum number of bits that need be transmitted in the time window for a satisfactory service.

obtained for the delay tolerant case for the example 1xEV-DV system as discussed in the previous sections. The dotted lines illustrate typical coverage curves that can be expected for services with different delay requirements when the proposed evaluation methodology is applied (they are projected lines – simulations have not been completed). A single value of outage is assumed for these curves. These curves needs to be obtained for several values of coverage and several values of outage (x) as suggested in the previous sections. As can be seen, once the curves are provided for all the other service parameter ranges, these plots provide the full picture of the type of services a system can support and the gaps in the system design to support such services.

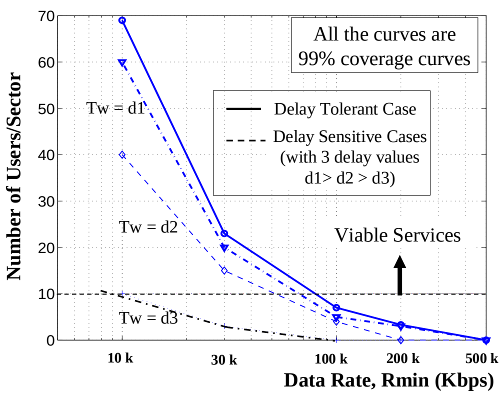

Figure 9 An Illustration of Multi-User Coverage Curves (99%) for Delay Sensitive Services

Conclusion

An important consideration for future wireless systems is to provide ubiquitous coverage for existing and emerging applications. This paper has addressed the limitations of current coverage metrics and proposed several extensions to the definition of coverage in the context of multimedia dedicated and shared channel systems, applicable to 3G Evolution and Next Generation Systems. The paper then proposes an associated set of evaluation methodologies covering both dedicated as well as shared channel based systems. The analysis is supported with several example simulation-based evaluations for systems with AMC-based shared channels for delay tolerant services. For delay sensitive services, the projected behavior is discussed, since simulation analysis is still in progress. The significance of "service coverage", and "viable service offering" in the context of multiple users has been illustrated.

The results show that the investigation of coverage improvement solutions is of paramount importance for future systems in order to ubiquitously support high QoS (low delay, high rate) services. Those coverage improvement techniques should be evaluated using the same standard set of proposed coverage metrics to reflect the end user performance for a range of service options. For example, the service coverage results obtained indicated that SHO provides only a little improvement (< 20%) for delay tolerant services (shared channel systems) although rate coverage curves indicated large (x2 to x3 times) gains. This shows the usefulness of the proposed evaluation methodology.

It is therefore recommended that the set of coverage metrics and the associated evaluation methodologies proposed in this document be included as part of the performance evaluation methodology of the next generation systems.

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