TRAFFIC GRADE OF SERVICE STANDARDS FOR CELLULAR MOBILE RADIO SYSTEMS - ISSUES AND APPROACHES

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While the traffic grade of service standards for the public switched telephone network are well established and widely accepted, similar standards for the public land mobile network have yet to be fully developed and recognized. This paper brings out the factors that must be considered when specifying the traffic grade of service parameters for public mobile telephone systems, and presents quantitative procedures for capturing the underlying tradeoffs.

1. INTRODUCTION

The advent of cellular technology has greatly enhanced the capacity and capability of public mobile telephone systems. The demand for mobile telephone service is growing rapidly, and a large number of public mobile telephone systems, based on the cellular technology, are being implemented around the world.

While the traffic grade of service (GOS) standards for the public switched telephone network (PSTN) are well established and widely accepted, similar standards for the public land mobile network (PLMN) have yet to be fully developed and recognized by the PLMN administrations. Such standards would not only ensure a uniform level of service to users as they move from one PLMN to another, but would also provide the necessary criteria for the planning and dimensioning of public mobile telephone systems. Throughout this paper it is assumed that PLMNs use cellular mobile radio technology.

Traffic GOS standards contribute to the quality of service that the subscribers will experience when gaining access to the system and placing a call. There are two stages that mobile subscribers must go through when they attempt to use the system. In the first stage, subscribers access the system by depressing a call initiation button, after keying in the desired number. The second stage refers to the session or conversation. The performance can be measured for both stages. Quality of access is measured by two parameters:

- call setup delay, which is a measure of the time the system takes to establish a connection; and
- blocking probability, which is the probability that the system is not able to establish a connection path.

Session quality is also measured by two types of parameters:

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• probability of unsuccessful handoff, which is the probability that the system will fail to handoff a call; and
• quality of transmission.

Since the latter falls under transmission standards, it will not be considered in this paper. Although blocking probability and call setup delay have similar parameters in the PSTN, the probability of unsuccessful handoff is particular to the PLMN.

Besides subscribers' requirements for acceptable quality of service levels, the specification of GOS parameters is influenced by such factors as cost/performance tradeoffs, technological limits, competitive pressures, and potential adverse impacts on the PSTN.

The purpose of this paper is to identify the issues in the setting of standards, as well as to suggest approaches for their specification. We will not define traffic GOS objectives for cellular systems. Section 2 provides a brief description of public mobile radio systems, and identifies the traffic GOS parameters that impact user perception of service and have a bearing on the performance and design of a PLMN. Section 3 presents a simulation-based methodology for setting traffic GOS standards which attempts to balance the total system cost and the quality of service provided to the subscribers. Section 4 briefly reviews the impact of ISDN-type services on traffic GOS for the PLMN. Concluding remarks are given in Section 5.

2. TRAFFIC GOS PARAMETERS IN A CELLULAR SYSTEM

2.1. Cellular Systems

Cellular systems provide public mobile telephone service which is reliable, has a quality and feature availability comparable to that provided by the PSTN, and accommodates a large number of subscribers. Cellular systems make very efficient use of the limited spectrum of frequencies allocated for mobile communications by reusing frequencies several times within a single metropolitan area. By dividing each radiotelephone service area into a grid of small zones (i.e., cells) with diameters of two to 30 km, frequencies may be used many times over within a given area. To avoid co-channel interference, each cell is allocated a set of frequencies different from those allocated to adjacent neighboring cells, and the cell's transmitter power is kept relatively low.

Each cell contains a computerized cell site controller and radio transmitting and receiving equipment which are connected by normal landlines to a mobile telephone exchange (MTX). This switching office establishes and controls connections between the PSTN and mobile subscribers, and between the mobile subscribers themselves.

Each cell transmitter monitors the strength of each mobile signal within the cell and, when the mobile subscriber moves from one cell to another, the MTX performs a "handoff" to the adjacent cell with the largest received signal strength. This provides uninterrupted service to the mobile subscriber. Figure 1 depicts the functional architecture of a typical cellular system. This figure shows the signalling and speech paths used to establish and carry a mobile call.
2.2. Call Setup Delay

A mobile subscriber who wants to communicate with another party in the PSTN (i.e. establish a mobile-to-land (MTL) call), or to another mobile (i.e. a mobile-to-mobile (MTM) call) must be assigned one radio frequency (RF) channel in his corresponding cell in order to complete his call. This is accomplished by a signaling sequence which is sent first over a dedicated access channel (radio data link) common to all subscribers in the system and, next, over a land data link which connects the subscriber's cell site controller to the MTX. Due to the nature of the access channel, it is possible to observe congestion and capacity waste when collisions occur. The random access signaling protocol is similar to the carrier sense multiple access with collision detection (CSMA-CD) scheme.

In the case of a terminating (i.e. land-to-mobile (LTM) call) a paging message is simultaneously sent by the MTX over the land data links to all cell site controllers in the coverage area. The controllers relay the paging message over the paging channels assigned to their cells and, once the called mobile has recognized its page, it responds over the access channel. The signaling sequence continues until an RF channel is allocated to the parties. The data link used for signaling is labelled as "1" in Figure 1.

We define the terminating call setup delay within a cellular system to be the elapsed time between the receipt of the last digit at the MTX from the serving CO and the return of an appropriate tone to the calling party. Originating call setup delay is defined to be the elapsed time between the activation of the send key by the mobile subscriber and the time the MTX outpulses the digits and the speech path is cut through to the MTX.

In any PLMN, call setup delay is one of the most important system performance criteria. The numerical limits of call setup delay standards would depend on the type of call (i.e. LTM, MTM, or MTL). The main factors which determine the delays experienced by a call being routed through the PLMN are:

- transmission delays for call initiation packets generated by mobile units (including retransmissions to resolve collisions)
- signaling delays on the land data link joining the MTX and each cell site controller
- switching delays in the MTX (usually quite minimal for digital switches).

2.3. Probability of Blocking on the RF Channel

The most limiting resource in a cellular system is the number of RF channels available in a given cell. Thus, the efficient use of the frequency spectrum is one of the most important issues in the system. The basic dimensioning problem in cellular systems is to decide how many RF channels are required in each cell to provide a prespecified blocking GOS. The voice channels (radio and land) are labelled as "2" in Figure 1.

The most common form of channel assignment is fixed channel assignment. In this scheme, RF channels are permanently allocated to a cell, and a cell may not borrow channels from other cells. The obvious problem with this method is that call volume is not spread evenly throughout the system and, consequently, there may be cells with low utilization. On the other hand, this method guarantees optimum reuse of channels because it is fixed. Although other channel assignment schemes such as dynamic, hybrid, and adaptive are possible, fixed channel assignment remains as the most widely used scheme internationally.
To visualize how the system works, imagine a cell with a pool of RF channels and four streams of arriving traffic, representing LTM, MTL, MTM, and handoff calls competing for the channels. In general, most cellular systems will give preference to handoff calls either by assigning them higher priority or by serving them on a delay basis. The other calls (i.e. LTM, MTL and MTM) are normally served on a loss basis. The two main factors that will have an impact on RF channel blocking performance are:

- volume and intrinsic characteristics (e.g. peakedness factor) of traffic offered to each cell; and
- rate of handoff calls into each of the cells.

The numerical limits of an RF channel blocking standard will depend upon the type of call. We define blocking for MTL calls within a cellular system as the probability that no free RF channel is available to provide a voice path between the calling mobile and the MTX. Similarly, blocking for LTM calls is defined as the probability that no RF channel is available to provide a voice channel between the MTX and the called mobile. Finally, we define blocking for MTM calls as the probability that no free RF channel is available to establish a voice path either between the calling mobile and the MTX or between the MTX and the called mobile, or both.

2.4. Probability of Blocking on PLMN to PSTN Circuits

With the exception of MTM calls, all cellular calls must pass through the PSTN. This accounts for more than 90 percent of the calls. There are a number of alternative architectures for the landline segment of the PLMN serving a metropolitan network. Among them we have: MTX serving the area with the status of a local exchange, and MTX being treated like a PABX, connected by a dedicated trunk group to a single local exchange. The most common type of interconnection is direct inward dialling/direct outward dialling (DID/DOD) to the local exchange. Standard teletraffic methods apply to these situations, provided the number and locations of the MTX and the cell site controllers are prespecified. We define blocking in the PLMN to PSTN circuits as the probability that no free circuit is available to establish a path between the PLMN and the PSTN. The blocking of the PLMN-PSTN interconnection trunks basically depends on the volume of traffic that is offered to the trunk group. It is well known that this traffic is usually smooth (i.e. a peakedness factor of less than one).

2.5. Probability of Unsuccessful Handoff

One of the unique characteristics of cellular systems is their ability to hand off calls in progress between cells. When a conversation is in progress, the RF channel power level of a mobile is monitored by the active cell site controller. If the signal drops below a predetermined level, indicating that the mobile may be leaving the cell, an automatic sequence of operations is initiated to hand off the call to a new cell. Some systems allow handoff not only because the signal strength has deteriorated, but also as a means of load balancing among cells [1]. Although present cellular systems do not have the capability to hand off a call to a cell controlled by another system, the possibility of providing this service has been under discussion for some time [2].

While cells are usually assumed to be hexagonal, they are not regularly shaped in practice due to terrain and radio signal factors and, normally, they overlap to some extent. This overlap provides a window during which the handoff can be completed without adversely affecting the quality of the connection.
We define the probability of unsuccessful handoff as the probability that a carried call will be exposed to bad service (i.e. a signal strength below -97 dBm) during a handoff attempt caused by the unavailability of a free RF channel in the receiving cell. Theoretically, reaching a bad service signal strength level does not necessarily mean that the call is cutoff.

The probability of an unsuccessful handoff is a critical parameter in a cellular system, as an unsuccessful handoff affects a call already in progress. As a cellular system matures, cell splitting will result in smaller cells and, so, more frequent handoffs. The frequency of handoffs will depend on factors such as cell size, average call holding time, average speed of the mobile user (which could vary with the time of the day, the area of the city, etc.), and geographical distribution of mobiles within the cell.
3.2. Setting RF Channel Blocking

Determining the number of RF channels needed for an acceptable GOS requires not only the consideration of traffic parameters and estimation of signal interference between cells, but also the assessment of factors such as cost/performance tradeoffs and potential impact on the PSTN. For example, a high probability of blocking on RF channels implies a cost savings on RF channel terminating equipment. However, this has to be balanced not only against user dissatisfaction, but also against the loss in real-time capacity at the MTX, and to some extent, at the local CO due to increased call reattempts.

All these factors make the design process, as well as the system performance evaluation, difficult to carry out with analytical techniques. Consequently, simulation testbeds are chosen to analyze cellular systems. The following results were obtained using a computer-aided simulation tool described in [4]. Figure 3 shows the relationship between the blocking on RF channels and equipment cost, revenue loss, and call processing capacity loss at the MTX. These results were obtained for a system of eight cells with 6000 subscribers, each with a loading of 0.033 erlangs (1.2 CCS). The costs are nominal estimates, and do not represent actual system prices quoted by the manufacturer.

Most of the PLMN administrations tend to offer a blocking GOS comparable to the one obtained in the PSTN, thus ranging from one to five percent, two percent being the most common.

3.3. Setting the Blocking on PLMN to PSTN Circuits

Technically, there is no difference between the PLMN to PSTN interconnecting circuits and the inter-exchange circuits in the PSTN. Although the most common means of interconnection between the PLMN and the PSTN would be through direct trunks, also interconnecting the MTX to a tandem office would make it possible to serve high volume traffic between both networks on a high-usage alternate routing basis. This type of arrangement may prove to be adequate should one of the interconnecting links fail. We consider that the inter-exchange blocking GOS objectives used in the PSTN to be directly applicable to the PLMN to PSTN circuits.

![Figure 3. Economics of RF Channel Blocking](image1)

![Figure 4. Handoff Performance](image2)
3.4. Setting Handoff Performance

The fact that the handoff performance will deteriorate with increasing system size (due to smaller cells resulting from cell splitting) should be reflected in the GOS requirements. The results depicted in Figure 4, which were obtained using the above mentioned simulator, depict the variation of handoff performance with respect to call holding time for three system sizes. The probability of a carried call encountering unsuccessful handoff increases with an increase in the system size, and also with the average call holding time. The GOS specifications for the handoff parameter need to be quite stringent, and how well and easily these requirements are met by a cellular system will depend on the efficiency and sophistication of the handoff algorithm. Today, the procedure used by cellular systems to accomplish handoff is not standardized, but rather reflects the design approach of each manufacturer. The basic principles are, however, common to all system designs. Poor handoff performance is a localized problem for the PLMN, with no substantial implications for the PSTN.

4. THE IMPACT OF ISDN-TYPE SERVICES ON THE PLMN

Cellular technology represents a first step towards ubiquitous personal communication in an integrated environment. The field of application for cellular systems is currently expanding. A growing demand for nonvoice services has already been detected in most of these systems around the world. Moreover, with the introduction of digital cellular technology in the near future, the span of nonvoice services will increase considerably. These new services (e.g. cellular data communications) will have traffic characteristics that differ markedly from those of mobile POTS traffic in two areas: holding time, and traffic pattern. Holding times will become longer, and traffic patterns will likely be peaky. These traffic characteristics will require, in general, additional facilities to provide the current GOS.

5. SUMMARY AND CONCLUDING REMARKS

In this paper, the problem of traffic GOS standards for cellular mobile radio systems have been discussed, and a number of issues that must be considered in their definition were presented. A simulation-based methodology for specifying these standards, which balances both the quality of service provided to the users and the cost of providing this quality, has been described. This methodology forms a basis for the development of traffic GOS standards for the PLMN.

REFERENCES


