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ANALYSIS OF RANDOM ACCESS CHANNEL IN GPRS SYSTEM INCLUDING THE CAPTURE EFFECT

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ABSTRACT

This paper presents the performance analysis of the access network for the general packet radio service (GPRS) system. Different quality of service (QoS) parameters, namely, probability of success, call failure probability, new packet arrival rate and instantaneous average number of slots occupied, are evaluated considering the effect of capture phenomenon. It is found that the system shows better performance under low capture ratio compared to the system using no capture.

1. INTRODUCTION

The need for data communication over mobile network has led to the new technology named like general packet radio service (GPRS). The rapid growth of this recent technology is due to the subscribers demand to access internet and intranet with handheld mobile set irrespective of time and place. The circuit switched data (CSD) or high speed circuit switched data (HSCSD) communication of GSM system cannot meet the quality of service (QoS) requirements of voice and data communication in the same structure. Therefore a packet based data system instead of circuit switched data system has become a bare necessity. GPRS offers an efficient utilization of radio resources in order to transfer user data packets between mobile stations and external packet data networks. The basic idea behind GPRS is to make use of the random access time slots of GSM access network unused from voice service to carry asynchronous data in a packet based fashion [1]. A definite objective of this technology is to share physical resources on a dynamic, flexible basis between packet data services and other GSM services [2].

In this paper, GPRS system structure and its functionality are discussed. Then the effect of capture on the performance of slotted ALOHA based packet random access channel (PRACH) network for GPRS system is investigated. The probability of successful capture, call failure probability (CFP), instantaneous average number of slots occupied by all GPRS data terminals and the new packet arrival rate are evaluated in the low capture environment as well as in the no capture environment.

2. SYSTEM STRUCTURE

GPRS system can be implemented in the existing GSM network by incorporating some additional network elements and by modifying some configurations of the existing network elements. A simple block diagram of GPRS network is given in Figure 1.

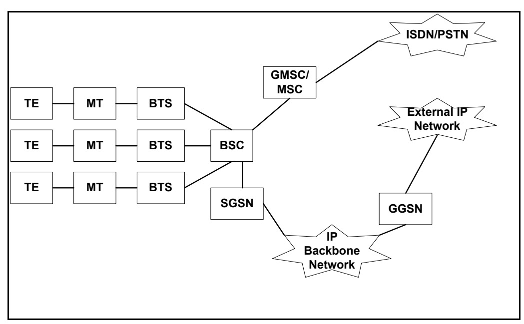

Fig. 1: Components of GPRS Network (HLR, VLR, AUC, EIR are not shown).

Some elements such as mobile terminal (MT), base station system (BSS), home location register (HLR), visitor location register (VLR), etc. of the existing GSM system are shared by the GPRS system [3]. Two new network elements are required to provide the packet data service, which are serving GPRS support node (SGSN) and gateway GPRS support node (GGSN). The SGSN connects the PRACH network with the IP backbone network. It forwards the incoming and outgoing data packet addressed to or from an MT that is attached within the SGSN service area. Other services that are provided by SGSN are session mobility and logical

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link management, output of billing data ciphering and authentication, etc. The GGSN provides the interface to the external IP network, session management, and routing operation of the external data to the subscriber's MT and the data generated in the MTs to the correct destination, etc. From the external IP network's point of view, the GGSN acts as a router of all the subscribers served by the GPRS network. In general, a GGSN is the interface to external packet data networks (PDN) for several SGSNs and an SGSN can route its packets over different GGSNs to reach destination of different PDNs.

The MT communicates with the terminal equipment (TE) (e.g. a laptop computer) and also with the base transceiver station (BTS). TE and MT are combinedly known as the mobile station (MS). In case of GPRS system, the MT and the base station centre (BSC) must be equipped with the appropriate software. A packet control unit (PCU) is installed in the BSS for controlling the GPRS mode and the radio link control/media access control (RLC/MAC) layer. When either voice or data traffic is originated at MS, it is transmitted to the BSC in the same way as a standard GSM call. At the output of the BSC the traffic is separated. Then the voice is sent to the MSC and data is sent to the SGSN.

In mobile communication, one or more carrier frequencies are assigned to each BTS. Each of these carrier frequencies is divided into 8 time slots that form a TDMA frame and each of these time slots is known as a physical channel. Physical channel in case of GPRS is known as the packet data channel (PDCH). In a cell that directly supports GPRS, a master PDCH (MPDCH) is allocated that provides control and signalling information to start data transfer both in up-link and in down-link and to handle the users mobility. An MPDCH incorporates a logical channel, known as PRACH for up-link transmission of channel request. If an MS wants to transmit, it requests through this PRACH. If possible then an IP number is given to the MS and it can then transmit packet data if data exists. In GSM, a physical channel i.e., a time slot is dedicated to an MS for the entire call period irrespective of whether data is being transmitted or not. But in GPRS a definite PDCH is not allocated to an MS. Rather it can use any of the PDCH if data is ready to transmit. So an MS can use any of the 8 PDCHs. Also several MSs can use the same PDCH. In a combined system of GSM and GPRS, few physical channels are allocated as PDCH and the remaining channels can be used for GSM. If the GSM is not using its physical channels, they can be allocated as PDCH. If afterwards, a channel is required for GSM operation, the GSM channels allocated previously as PDCH will now be allocated for GSM operation, i.e., a priority is given to the GSM voice calls. This approach of allocation channel is dynamic. If the MS, which has obtained an IP number, now generates a data packet, the network will forward this to its address on the first available PDCH. After the transmission of the packet, the channel will be released and will be reallocated again when data packets are ready to transmit. This provides a much better utilization of the traffic channel.

3. SYSTEM ANALYSIS

In GPRS an MS sets a request for a traffic channel by sending a test packet through PRACH which is based on slotted ALOHA protocol. Now if there are other MSs trying to transmit packets simultaneously, a packet collision will result. In this case, a test packet from n+1 interfering packets can be captured if its power P_t is larger than z times the combined power of all other interfering packets, P_n, where z ($z \geq 1$) is defined as the capture ratio. In the no capture environment the transmission of a packet will be successful if and only if one user transmits a packet in the given time slot, otherwise collisions will occur among the test packets so that all the test packets are lost. In the capture environment, a packet can be received correctly even if there are some other interfering packets in the same time slot. Thus in the capture environment the probability of successful capture of a test packet increases reasonably than that in the no capture environment.

The stability of the access system depends upon the optimum value of the aggregate traffic generation rate G with respect to the new packet generation rate λ and the number of retransmission L. It is found that a slotted ALOHA system is mono-stable in no capture environment for any value of the new packet generation probability and retransmission probability, if the number of retransmission L is limited to, at most, eight [4]. The optimum value of G is that for which the throughput S is maximum. Beyond this optimum value of G, the throughput S starts decreasing. Now for the maximum throughput condition, the optimum value of the aggregate traffic generation rate can be obtained as

$$G_{op} = 1 + \frac{1}{z} \quad (1)$$

It is noted that the optimum value of G for maximum throughput without capture is 1 and that in the best capture environment (z = 1) is 2.

In our analysis, we assumed that new packet arrival rate of all active *MS*s is equal., hence the aggregate traffic generation rate of any *MS* in a given time slot is equal. It is also assumed that the system is memoryless as the probability of transmitting a packet in a given time slot is independent of the state of the previous slot(s) [3].

The unconditional probability of successful capture of a test packet, *Pc(Su)* is given by

$$P_C(Su) = \exp\left(-G\frac{z}{1+z}\right) \quad (2)$$

Again the new packet generation rate is given by

$$\lambda = \frac{G\exp\left(-G\frac{z}{1+z}\right)}{1-\left\{1-\exp\left(-G\frac{z}{1+z}\right)\right\}^{8}} \quad (3)$$

Call failure in the GPRS access network can occur when access is denied by the PRACH. The call failure probability (CFP) is given by

$$CFP = \left\{1-\exp\left(-G\frac{z}{z+1}\right)\right\}^{8} \quad (4)$$

The instantaneous average number of slots occupied by all data terminals is given by

$$U_{PTCH} = S_{PRACH}.h.a.q.\left[1-\left\{\sum_{k=0}^{D}\left(S_{PRACH}.h\right)^{k}/k!\right\}^{-1}.\frac{\left(S_{PRACH}\right)^{D}}{D!}\right] \quad (5)$$

where *D* is the maximum GPRS terminals allowed to access the system simultaneously, *h* is the exponentially distributed GPRS terminal transmission time in minute, *a* is the data traffic activity factor and *q* is the maximum number of slots allocated to each GPRS terminal. According to *GPRS* specifications $q = 8$.

The throughput of access network based on the slotted *ALOHA* is given by [5]

$$S_{PRACH} = \lambda\left[1-\left\{1-\exp\left(-G\frac{z}{z+1}\right)\right\}^{8}\right] \quad (6)$$

Using equation (1) in equation (6), we obtain the maximum throughput as

$$S_{PRACH}(\max) = 0.9745\lambda = 0.3678\left(1+\frac{1}{z}\right) \quad (7)$$

Putting the value of $S_{PRATCH}(\max)$ in equation (5), we obtain U_{PTCH} for maximum throughput as

$$U_{PTCH(\max)} = 2.943(1+1/z).h.a.\left[\begin{array}{l}1-\left\{\sum_{k=0}^{D}\{0.3678(1+1/z).h\}^{k}/k!\right\}^{-1}\\ \times\frac{\{0.3678(1+1/z).h\}^{D}}{D!}\end{array}\right] \quad (8)$$

4. RESULTS AND DISCUSSION

Now different performance parameters of a GPRS access network are evaluated considering the capture effect. Figure 2 shows the variation of the probability of successful capture, *Pc(Su)*, with the aggregate traffic generation rate, *G*. It is observed that *Pc(Su)* decreases almost linearly with *G* for a fixed value of capture ratio, *z*. Again, for a fixed value of *G*, as the capture ratio decreases, i.e., as we use more capture, *Pc(Su)* increases reasonably. *Pc(Su)* is the lowest for the no capture condition.

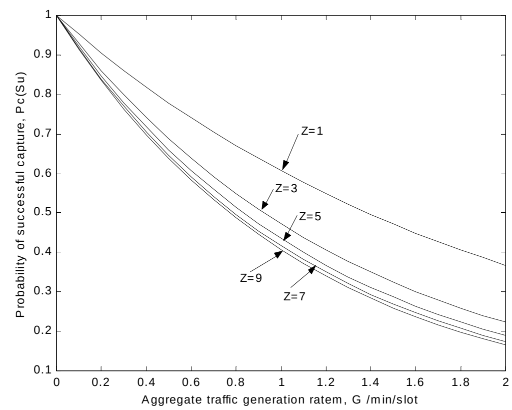

Fig. 2: Probability of successful capture with aggregate traffic generation rate

Figure 3 depicts the variation of new packet arrival rate, λ, with respect to the aggregate traffic generation rate, *G*. It is observed that upto a certain value of *G* (about $G = 1.2$), λ increases for a fixed value of capture ratio. Beyond $G = 1.2$, λ becomes almost independent of *G*. For a fixed value of *G*, as z increases λ decreases. So if we use capture, λ increases.

Variation of CFP, *R,* is shown with respect to the aggregate traffic generation rate, *G*, in figure 4. It is seen that up to a certain value of *G*, such as $G = 0.8$, *R* is almost zero whether capture is used or not. Beyond this value of *G*, *R* starts to increase. *R* is the highest in the no capture (*z* is infinite) environment and lower in the low capture environment (such as, for *z*=1).

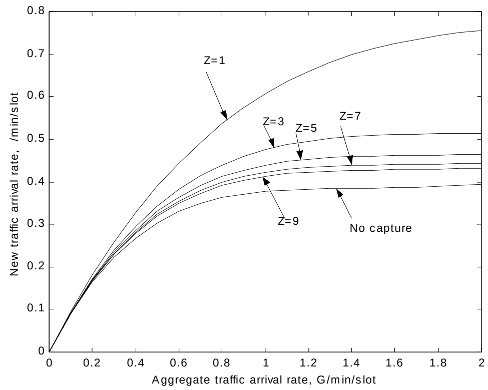

Fig. 3: New traffic generation rate with aggregate traffic generation rate

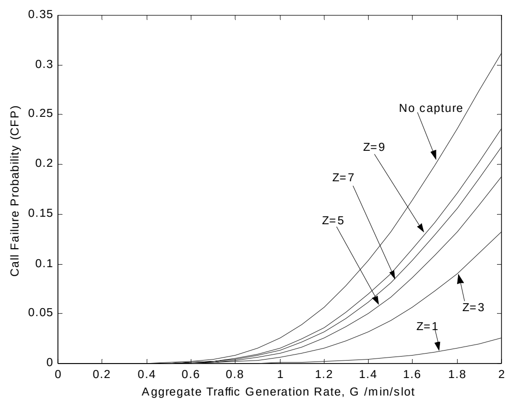

Fig. 4: Call failure probability with aggregate traffic generation rate

Figure 5 gives the variation of instantaneous average number of slots occupied by all GPRS data terminals, U_{PTCH}(max), for the case of maximum throughput with respect to the capture ratio, *z*. It is observed that up to a certain value of *z* (about *z*=10), as *z* increases for a fixed value of *D*, *a* and *h*, U_{PTCH}(max) decreases. Beyond *z*=10, U_{PTCH}(max) becomes almost independent of *z*. Again, for a fixed value of *z*, as *h* increases, U_{PTCH}(max) increases. This is also true for *D*, i.e., as *D* increases for a fixed value of *z*, U_{PTCH}(max) increases.

5. CONCLUSION

In this paper, the performance of the access network for GPRS based on the slotted ALOHA protocol is analysed under capture environment. It is seen that if capture is used in the access network, both the probability of success of test packet and the instantaneous average number of slots occupied by all GPRS terminals are significantly improved. Also the call failure probability is considerably reduced. This makes the utilization of the resources efficient. So if a low capture is introduced in the access network of GPRS, the system QoS improves significantly which is required for reliable operation of the GPRS system.

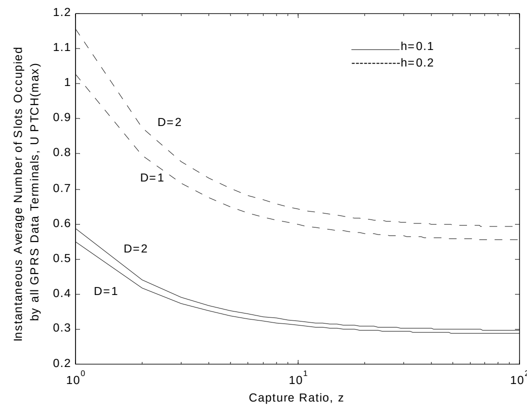

Fig. 5: Instantaneous average number of slots occupied by all *GPRS* data terminals with capture ratio

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