PERFORMANCE EVALUATION OF EDGE UNDER S-ALOHA AND ADAPTIVE TRAFFIC LOAD S-ALOHA RANDOM ACCESS PROTOCOLS

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Abstract- In this paper we make a performance evaluation of the air interface system EDGE (Enhanced Data Rate for GSM Evolution) introducing the Adaptive Traffic Load (ATL) S-ALOHA as the random access protocol. The EDGE system originally considers the S-ALOHA random access protocol to let users access the network for transmitting their data packets. However, S-ALOHA becomes unstable for high traffic loads rendering very low throughput not allowing any user in the network to successfully transmit a packet. In this way, even if the EDGE system has sufficient capacity to give service to the users, system throughput would still be very low since no user can access the network. By introducing the ATL S-ALOHA protocol, we maintain the access throughput constant at the maximum value allowing users to access the network to transmit their data packets even at very high traffic loads. We evaluate the performance of the EDGE system in terms of average data rate and packet delay for both S-ALOHA and ATL S-ALOHA as the random access protocol.

Keywords: S-ALOHA, Adaptive Traffic Load, Packet Delay, EDGE.

I. INTRODUCTION

The fast evolution of Internet and digital communications systems such as IS-136 and GSM, has lead to the introduction of data services in addition to the voice services already offered by this systems. EDGE is an air interface based on Time Division Multiple Access (TDMA) and is proposed as the evolution of TDMA based second generation networks to offer packet data transmission in order to provide the 3G services [1]-[4].

In EGPRS system which uses EDGE air interface and is based on GSM system, slotted ALOHA protocol is used in order to enter the system and be assigned a traffic contentionless channel. EDGE uses the Packet Access Random Channel (PRACH) to transmit the request of the users to enter the system [5]. Due to the bursty characteristic of data traffic, the access technologies should be able to allocate a large amount of resources in a decentralized way to reduce delay and increase throughput [6]. ALOHA random multiple access are widely used in data networks since it is the most simple protocol and their implementation is straightforward. It is a technique that allows users to transmit their data packets over a common channel in either slotted or unslotted form whenever it has a packet ready to transmit. In Slotted ALOHA, the access channel is divided into fixed length time slots where the packets are transmitted. All transmitters in the network are allowed to transmit only at the beginning of the slot to avoid any collisions with the packets transmitted in the previous slot. Nonetheless, it has very poor performance in terms of throughput[1] for high arrival rates since, in that circumstances, it becomes unstable, not allowing any user in the network to successfully transmit a packet. Also, due to the introduction of new services as e-mail, video and web browsing in addition to the voice services, the traffic load is expected to increase even further. Slotted ALOHA protocol achieves a maximum throughput of 36% for a normalized offered load of 1 packet per packet transmission time, the complete analysis is shown in [7]-[9]. For high offered loads, the amount of collisions increases drastically, and for each collision at least two users have to retransmit their packet or are blocked. This means that when traffic load is very high the current random access protocol in EGPRS may not allow any user to successfully enter the system and gain a data channel. In this conditions, when there is a considerable number of users requesting service, and even if EGPRS has sufficient capacity to provide service to many data users, system occupation is very low and few users can actually transmit, rendering a very low channel utilization.

We have introduced in [10] the Adaptive Traffic Load S-ALOHA random access protocol which maintains the maximum slotted ALOHA throughput for all traffic loads g higher than 1 packet per time slot regardless of the actual value of the traffic load. The basic idea consists on allowing the portion of users that generate a traffic load gmax to attempt transmission of their packets, while the rest of the users have to wait for a random time to attempt their transmission. However, our previous work does not evaluate the system performance as it is only focused on the random access channel. EDGE system performance has been extensively analyzed in [1]-[4], however the random access protocol is not considered, this means, that it is assumed that users somehow accessed the network in a previous stage. These analyses are focused on the data packet delay for a number of users requesting service already in the system. With the current access protocol in EGPRS however, it can not be guaranteed that the system can have this number of users in the system since S-ALOHA may become unstable for high traffic loads, rendering this analysis incomplete.

^Throughput is defined as the portion of time that the access channel is transmitting useful packets.
It is the objective of this paper to analyze the behavior of the EDGE air interface when the random access protocol is considered, since performance of the system will be greatly affected by the throughput in the access channel. We also compare the results when ATL S-ALOHA is introduced to the system. Additionally, we analyze the behavior of the S-ALOHA random access protocol, in terms of throughput and access delay for data users, under long-range-dependent traffic when the initial access is stabilized by using Adaptive Traffic Load. Since data services have very different characteristics than conventional voice services, it is of great importance to analyze the performance of this protocol under long-range-dependent traffic. The rest of the article is organized as follows. The EDGE air interface is described in section II. In section III, we present the basic access method for the system and the basic idea of Adaptive Traffic Load. Simulation model for the EDGE system as well as the access procedure is explained in section IV. In section V, we present some numerical results from the simulations and conclusions are drawn in section VI.

II. EDGE Radio Interface.

A. Modulation and Codification.

EDGE reaches higher data bit rates by introducing a new modulation scheme 8PSK in addition to the GMSK modulation. For each modulation scheme in combination with four codification schemes EDGE has eight different data bit rates ranging from 11.2 Kbps to 65.2 Kbps as shown in table 1. Each of the data bit rates has different vulnerability to errors depending on the codification rate. In this way for low codification rate, EDGE has high data rate but is more vulnerable to errors. On the other hand, for high codification rate, we have low data rate but the packets are less vulnerable to errors.

B. Radio Link Control.

EDGE uses radio link control in order to make a more efficient use of the radio spectrum. Radio link control adapts the bit data rate according to the quality of the link based on the CIR measurement. Radio link control ensures the maximum performance of each individual radio link by choosing adaptively the modulation and codification scheme with the higher data rate that provides the fewer block error rate according to (1).

\[ S_n = R_n \left( 1 - \text{BLER} \left( \frac{C}{I} \right) \right) \]  

(1)

Where \( R_n \) is the modulation and codification scheme, \( \text{BLER} \) is the Block error rate and \( C/I \) is the Carrier to noise ratio.

C. Frame Structure.

EDGE uses the same time slot and frame structure as GSM. GSM frame is 4.615 ms with eight time slots per carrier. The logical data unit is a RLC block coded and interleaved over four consecutive GSM frames. Each LLC PDU is divided in the necessary number of RLC blocks, each of which is 20 ms. The access time slot is also 4.615 ms. In [1, 2] are given all the characteristics and features of EDGE such as the modulation, codification, the time slot structure, and link adaptation.

III BASIC ACCESS METHOD

Random access protocols such as S-ALOHA become unstable when the arrival rate increases, namely for a traffic load higher than the traffic load \( g_{\text{max}} \) for which the throughput is maximum. In [10], we presented the ATL algorithm to stabilize the random access protocols. The basic idea consists on allowing the portion of users that generate a traffic load \( g_{\text{max}} \) to attempt transmission of their packets, while the rest of the users have to wait for a random time to attempt their transmission. Each arrival is permitted to access the random access channel with probability \( p(g) = \frac{g_{\text{max}}}{g} \) and attempt to access in a later time with probability \( q(g) = 1 - p(g) \). Notice that these probabilities depend on the current traffic load. Hence the traffic load that actually attempt to access the network is \( g_{\text{max}} \) and the throughput for the ATL protocols is maintained at the value of \( g_{\text{max}} \) for \( g > g_{\text{max}} \). For traffic loads lower or equal to the traffic load \( g_{\text{max}} \), ATL behaves in the same way as the conventional medium access protocol since all users that arrive at the system are allowed to attempt transmissions with probability 1. For \( g > g_{\text{max}} \), by assigning an authorization probability to transmit to the arrival process we are making a subdivision of a Poisson process which is also a Poisson process with mean \( g_{\text{max}} \) [11].

For S-ALOHA it is well known that the throughput is [7]

\[ S_{\text{ALOHA}} = g T e^{-gT} \]  

(2)

hence, for ATL S-ALOHA we get a throughput given by [10]:

\[ S_{\text{ATL-S-ALOHA}} = g_{\text{max}} T e^{-g_{\text{max}}T} \]  

(3)

where \( g_{\text{max}} = 1/T \), therefore:

\[ S_{\text{ATL-S-ALOHA}} = \sqrt{g_{\text{max}}} \]  

(4)

We can see form (4) that throughput remains constant for traffic loads higher than \( g_{\text{max}} \), maintaining the system stable at the maximum throughput regardless of the traffic load. A more detailed analysis is presented in [10].

As a first approximation to study the effect of the long-range-dependent model on the S-ALOHA protocol we consider two access channels. We consider a channel where traffic is Poisson (we call it first access channel), that is, packet inter-arrival times are exponentially distributed random times. Additionally, we consider an access channel where traffic is long-range-dependent (we call it second access channel), that is, packet inter-arrival times for each user are Pareto distributed random times. Hence, we separate access according to the traffic model in the sense that for the first

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access channel we only have arrivals following a Poisson process, and for the second access channel we only have long-range-dependent distributed random times. This separation may seem artificial, but we are only proposing it to have a better insight in the behavior of the system under LRD traffic and not for practical implementation purposes. In next section we will consider a more realistic model.

In the first access channel users that have not yet transmitted any packet in the system arrive, that is users who initiate a session. In the second access channel we have arrivals from users that have more data files to download and they transmit an access packet to contend for a data channel in the network. Once a user has transmitted a successful packet in the first access channel, he gains access to a collision-less data channel in the system and downloads his data. When transmission is finished he releases the data channel. For subsequent files, he has to gain access in the second access channel. Since S-ALOHA protocols have been extensively studied under a Poisson process, we find it very useful to study this protocol only under a long-range-dependent traffic model. Therefore we are not implementing the complete EDGE system at this point except for the random access channel frame, that is, we are not considering the modulation and codification schemes or the link adaptation of the system. We only model the data transmission according to an ON-OFF model where the ON period has a Pareto distribution with minimum download time of 0.714 sec which accounts for the data download of a 1 kbyte file at the minimum data rate of the system (11.2 kbps). The OFF period distribution is based on the user’s reading time, where the minimum time required by the user to read a web page is considered to be of 30 seconds. The time that a user remains in the system corresponds to an exponential distributed random time.

IV. SIMULATION MODELS

All simulations are at the system level, so there is no simulation of the physical layer. Co-channel interference is assumed to be much higher than thermal noise, that is interference limited system. The introduction of EDGE in a GSM environment is transparent since they have the same frame structure and channel bandwidth.

A. General Simulation Model.

The simulation environment consists of 49 regular hexagonal cells with three sectors per cell. A standard 3 frequency reuse pattern is used, so there are three sectors per cluster with four carriers per sector and eight time slots per carrier. Distance attenuation is calculated from (5), considering log-normal fading with 6 dB standard deviation.

\[ L = C + 35 \times \log(d) \]  

(5)

All users are actively generated randomly in all the simulation area. Each user selects the serving base station according to less trajectory losses with 3dB uncertainty margin due to handoff. No antenna diversity is used.

Internet traffic is highly asymmetric, that is, most data is coming in the downlink direction while in the uplink direction there is only acknowledgements and some control information, therefore only the downlink channel is consider throughout the simulations.

Users enter and leave the system during the simulations. All users enter the system with certain probability and the ones that enter and find available resources start their packet transmission. No mobility is simulated, users die in the same position as they started they transmission.

Carrier to noise ratio is measured every 20 ms on all active users of the system. Based on the CIR and the modulation and codification scheme errors are generated randomly in order to decide whether the transmission was successful or not. If an error is detected in a block, a retransmission of that block is requested.

B. Traffic Model.

The traffic model is based on the WWW traffic. Users enter the system according to a Poisson process and the duration of each session is exponentially distributed [12], [13]. The active users transmit data packets according to an ON-OFF model until the session time is over. The time between packets (OFF period) is random with a Pareto distribution with minimum value of 30 seconds that represent the user reading time (parameter \( v = 1.5 \) to account for the infinite variance). The size of each packet is also random with Pareto distribution with minimum size of 1000 bytes (parameter \( v = 1.5 \)). The size of the packets is limited to 100 Kbytes for two reasons. First, because mobile users are not likely to request large amounts of information, and second, to limit the simulation times.

C. Link Adaptation.

All active users in the system choose the modulation and codification scheme in each update period according to the radio link control mentioned on section II. The update period is 200 ms or 10 RLC blocks. The CIR used in the update is the CIR measured in the last RLC block successfully received. The quality link model estimates certain errors on the CIR measurements by adding a normally distributed error with mean of 2 dB before data rate selection.

D. Admission Control.

Every 20 ms EDGE transmits 4 Packet Random Access Channels (PRACH), one for each GSM frame of 4.615 ms. Then there are 4 opportunities to access the channel in 20 ms. For S-ALOHA and ATL S-ALOHA, we consider the traffic as the access time slot since at most one packet can be correctly transmitted in this time.

A more realistic model that that presented in section III is considering a unique access channel where all users most transmit their access packets and also implement the complete EDGE system as described early in this section. New users arrive according to a Poisson traffic to the system. If they transmit the access packet successfully, i.e. they were allowed by the ATL protocol to transmit and no collision occurred during transmission, they access the system and request a data channel. Otherwise they retransmit their access packet in an exponential random time. Once the user has accessed the system, a traffic channel is allocated to that user if there is at least one time slot free and data transmission is done.
considering the simulation model already described. In other case, the user has to retransmit in an exponential distributed random time. One of the most important characteristics of data packet networks is that resources can be allocated to other users whenever they are not transmitting any data. Hence, users that download their files successfully release the data channel during the OFF period, and that channel is allocated to another user with data to transmit. If active users in the OFF period have more data to download, they have to contend for a data channel again.

V. NUMERICAL RESULTS

For the first simulations explained in section III, we consider that the EGPRS system has enough capacity to service all users accessing successfully through the access channels, hence, we consider a non-blocking system. Link adaptation is not considered in the access channels or in the data channels. Both access channels have the same parameters and are completely independent from each other. Data channel assignment is on a packet basis, rather than circuit switched bases. If he wants to download another document or keep browsing web pages, he has to contend for a data channel in the second access channel.

We can see in figure 1, the throughput for the S-ALOHA protocol for the Poisson model and the bursty traffic model with different random session times. For the Poisson traffic (first access channel), throughput does not vary for different session times since we consider an infinite population of users initiating a session in the system and this channel is only use for the first access. For the second access channel, when the average session time (ST) in the bursty traffic model is small (100 sec), throughput is lower than for the Poisson case since the number of users actively transmitting is very low rendering a low activity factor in the second access channel. However, when ST is augmenting, it is clear that the number of active users in the second access channel is augmenting too, and the S-ALOHA protocol is perfectly capable of attending the traffic load, even if the nature of the traffic is bursty, giving a much higher throughput than in the Poisson traffic. With this in mind, we can conclude that in the second access channel, the S-ALOHA protocol is always operating in the stable region, where collisions are maintained low. As we increment the average session time, throughput for the second channel is incremented until a certain limit, where it will not be further increased. This is because for very high ST (around 10000 sec) all users accessing successfully to the system, remain active in the second access channel transmitting, and will not leave the system for the duration of the simulation. For practical systems however, session times are expected to be low, in the order of a few minutes, hence we can see that the amount of traffic generated by the users already registered in the system is not comparable with the traffic load generated by the new users arriving to the system, which led us to believe that the impact of the LRD traffic in the access channel will not be considerable. This would not be true if we consider a long session time, in the order of hours, which is not expected to happen often in a cellular environment.

Figure 1. Throughput for Slotted ALOHA for Poisson traffic and Long-Range-Dependent Traffic.

For the complete EDGE system simulations, we consider the model depicted in section IV, where we only have a single access channel where the arrival process is a combination of a Poisson process and a ON-OFF model, link adaptation is not implemented in the access channels but it is implemented for the data channel transmission. In figure 2 we show the results for the throughput in the access channel with S-ALOHA and ATL S-ALOHA. Throughput has the basic behavior as in the Poisson traffic due to the small contribution of users transmitting with an ON-OFF traffic model, since session times are relatively small. This allow us to implement the ATL protocol for all users in the system attempting to transmit an access packet maintaining the system stable and at the maximum value of throughput.

We also show results for the packet delay in figure 3. This is the time that takes the system to transmit successfully a data packet from the moment it is generated until it has been completely received. Consequently, this packet delay will be affected by the time it takes for users to access the system successfully and request a data channel, i.e., the access delay. When the S-ALOHA protocol is being used, the system becomes unstable for high arrival rates due to a high number of collisions, therefore, it will take longer for users to access the network, incrementing the packet delay. If ATL S-ALOHA is implemented, access delay will increase linearly with the traffic load as opposed as the exponential increase in the conventional protocol, maintaining the packet delay low.

Finally, another important factor to consider is the channel utilization, that is, the mean data rate per time slot in the system. In ideal conditions, all time slots would be occupied at all times, regardless of the traffic load, and all users would be transmitting at the highest data rate rendering an utilization of 65.2 kbps. Channel utilization is affected by basically two factors. For one, time slots are not always occupied since there are not a big number of users accessing the system or, there are a lot of users requesting a data channel generating a high traffic load that the access protocol cannot handle, hence allowing a low number of users into the network. In figure 4 we can see that when traffic load is low, channel utilization is also low since there are a lot of time slots empty. As the traffic
load is increased, also the channel utilization is increased. When S-ALOHA is used, the number of users that transmit their access packet successfully decreases for high arrival rates, hence allowing a small number of users into the network causing a low channel utilization. However, if ATL is implemented, the number of users that access the network is maintained constant, therefore, channel utilization is also kept constant. The other factor that affects channel utilization is the interference level suffered by the data channels. That is, for users with a low CIR level, will transmit data packets with a low data rate, rendering also a low channel utilization.

VI. CONCLUSIONS

We have introduced a LRD traffic in the S-ALOHA protocol and analyze its behavior separately from the Poisson traffic. Traffic load generated by the users already transmitting in the system is not very high when the session times are in the order of a few minutes, therefore, the access procedure can still be stabilized by the introduction of the ATL protocol. Packet Delay is also maintained at a low level when ATL is introduced since access delay is increased linearly with the traffic load as opposed to exponentially as is the case for the conventional protocol. Packet Delay is also affected by the

CIR conditions of the system since users with higher CIR can download their files much faster than users with a poor channel condition. Finally, channel utilization is degraded for high arrival rates when the conventional access protocol is implemented, this is because the number of users that can access the network in this conditions is very low, while ATL maintains this number constant, also maintaining the channel utilization constant.

References