Signaling enhancement for Machine Type Communications in GERAN using Orthogonal Sub-channels

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***Abstract*—Machine type communications have emerged with new types of applications and revenue sources both for network operators and cellular/network equipment companies. This new kind of service may increase significantly the number of devices accessing the network in the next few years, and could have some impacts over the current services, namely normal voice and data services. One important concern is related to effects of extreme cases where MTC devices may act in a synchronized way. In GSM networks, the signaling capacity may be temporarily blocked, limiting the access of normal services for some seconds, or even minutes. This paper proposes one solution for overload problem caused by MTC device synchronization using the Orthogonal sub-channels technique (OSC). Statistical analysis over the effects of synchronized MTC devices are used to provide an overview on the achievable access procedure delay reduction when using this technique. The proposed technique has proven to decrease the average delay of normal services by 70% and to reduce by 50% the overload period of the signaling channels.**

I. Introduction

Due to its increased importance, studies on network enhancements for Machine type communications (MTC) have been developed in standardization forums [1]. It is expected that in the next years, there will be approximately 20 MTC devices for each normal mobile phone, which means that MTC traffic will take an important share of radio resources, and may degrade performance of normal traffic.

A study item is opened at GERAN for MTC enhancements for GSM [2]. The focus of this study item is on enhancements for applications requiring low data throughput, low cost, and wide coverage. The main application example are the smart meters, which report measurements of electricity, gas, heat, water, etc., for a central station gathering this information for charging each user.

In some of the MTC applications, it is expected that the service provider using MTC devices, e.g. electricity company, will require synchronized measurements. This could be required when there is the need for this information for controlling electricity grid parameters, e.g. in smart grid [3], or for reporting user status in real time. This kind of synchronization is not something expected to happen in nowadays' GSM networks, hence problems could arise by time concentrated bursts with large number of access requests [4], [5], [6].

The access channels may be an important bottleneck when MTC start to be widely deployed in wireless networks. As the MTC traffic increases, there is a high probability that the number of accesses will increase significantly, since the MTC devices behave in a different manner than the mobile stations (MSs) with normal traffic. In some applications, the MTC devices are expected to carry information using periodical messages with very low amount of data mostly in uplink (UL). This leads to a higher number of accesses than what is expected by a normal MS. Additionally, the MTC devices may act in a synchronized way. This may cause an overflow of accesses during specific time instants, which can overload and block the signaling channels for some time. Altogether, this behavior of MTC devices could affect the performance of normal MSs, since the calls starting during the overflow periods could have their latency increased by several seconds.

Orthogonal sub-channels (OSC) is a feature under standardization for increasing voice capacity in GSM networks [7]. It enables communication with two users in the same channel simultaneously. GERAN feasibility studies focused on determining new training sequences for optimizing capacity improvement as well as new transmit pulse shapes. Additionally, new features related to this concept were developed and are being studied in GERAN over the VAMOS working item [8]. Applications of this technique include increasing the voice capacity in overloaded networks, refarming GSM spectrum for newer technologies [9], and even improvement of perceived voice quality in some specific network scenarios [10]. Additionally, important studies concentrate on new receivers designed to maximize OSC performance [11], [12].

This paper shows a solution for signaling overload in access procedure channels when synchronized MTC users are present in a GSM/EGPRS network. The proposed solution combines the concept of orthogonal sub-channels, which were originally under development for speech channels, for extending the access channels capacity. Simulation results are provided in order to prove the effectiveness of the proposed solution, which show that the method is able to decrease significantly the access procedure delay, for most users.

This paper is organized as follows. Section II-C presents details on the implementation of the proposed concept. The

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simulation assumptions and related details are described in Section III. The simulation results showing the possible improvements brought by the proposed technique are shown in Section IV. Section V closes the paper with the conclusions.

II. Signaling improvement with orthogonal sub-channels

A. Orthogonal sub-channels

The orthogonal sub-channels (OSC) is a technique under standardization process for speech traffic channels [8], in which two users are enabled to transmit in the same channel simultaneously by using different training sequences (TSC). By using this technique in half-rate channels, up to 4 users can share the same resource. In uplink (UL) direction, two users transmit a normal GMSK signal and the transceiver (TRX) in the base transceiver station (BTS) is able to separate both signals by using interference cancellation techniques jointly with the different TSCs. In downlink (DL), a composite 8PSK signal is sent for both users and the MSs use the different TSCs to decode the desired orthogonal component, in which symbols for each user are presented either in the inphase or quadrature components as in Fig. 1.

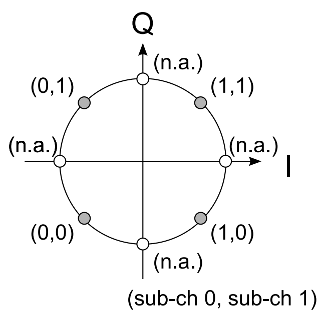


Fig. 1. 8PSK constellation symbols used on OSC (adapted from [13]).

B. Random access procedure

The random access procedure is used when user initiated calls are started. In this case, the MS sends a message in UL in the random access channel (RACH) requesting resources. In a second step, the network sends a message in the access grant channel (AGCH) with the immediate assignment (in case resources are available) or an immediate assignment reject. After each RACH transmission, the MS waits for a immediate assignment. If it is not obtained, the RACH burst is retransmitted after a random number of TDMA frames between S and $S+T-1$, where S is the minimum delay between retransmissions, and T controls how randomly spread the retransmissions are.

C. Concept description

In the method proposed, the random access channel (RACH) and the access grant channel (AGCH) capacity is increased by using orthogonal sub-channel (OSC) concept. In UL direction RACH capacity is increased by enabling more than 1 TSC to be used. The possible RACH TSCs should be broadcasted in the broadcast control channel (BCCH) or other control channel as shown in Fig. 2. Once a MS starting access to the network is aware of the available TSCs, it should choose one randomly before attempting RACH transmission. By enabling multiple TSCs in RACH, the BTS may be able to decode multiple simultaneous RACH transmissions of the users using different training sequences.

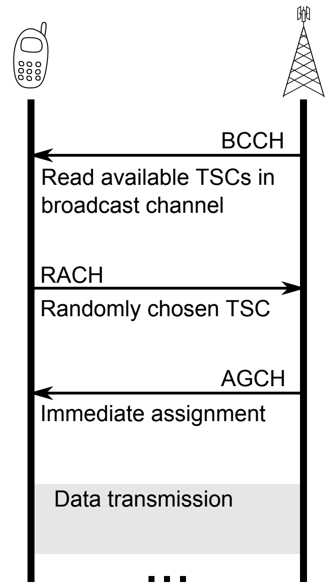


Fig. 2. Time diagram describing the random access enhancement using OSC.

Fig. 3 (a) shows an example in which two users are trying to send RACH at the same time with equal TSCs. In that case it is most likely that the BTS won't be able to decode both signals, and one of them could be decoded if it is sufficiently stronger than the other. On the other hand, by enabling multiple TSCs for RACH, there is a high probability that RACH collisions occur with different TSCs as in Fig. 3 (b). In that case, the UL receiver will have better chances to estimate the channels for each received signal and decode multiple RACH messages properly. The maximum number of decoded messages will depend on the receiver type in UL, number of antennas, as well as the number of TSCs enabled. Additionally, for optimum performance of this concept, TSCs enabled in the same BTS should be as close to orthogonal as possible.

In DL direction, the AGCH capacity improvement is also achieved by using OSC concept. In that case, each user would need to know beforehand which is the TSC they have to equalize in AGCH. This could be linked to the TSC that was already used in RACH. Thus, it is possible to increase the AGCH capacity up to two times, depending on the MS receiver type and the radio conditions. It is important to notice though, that not all DL receivers will have good performance in OSC channels. It is often required the use of an interference cancellation technique, such as single-antenna interference cancellation [14], [15]. Hence, an algorithm should

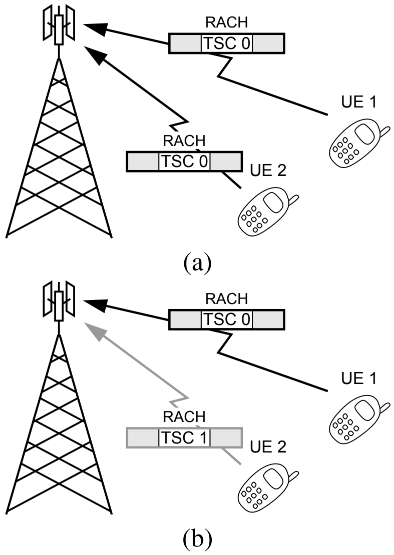


Fig. 3. RACH behavior when two users are trying to access the network simultaneously. (a) With one TSC there is a high probability of RACH error. (b) With two TSCs BTS may be able to equalize and decode both messages independently.

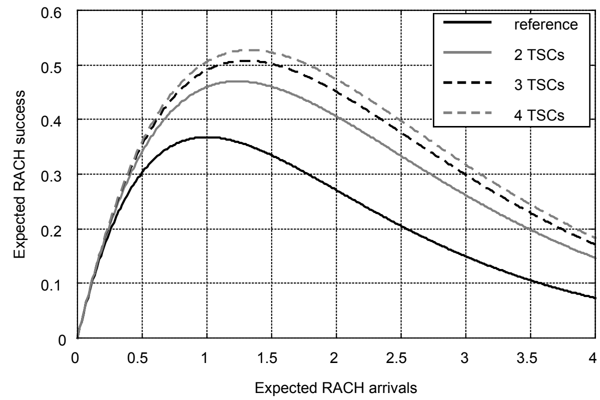


Fig. 4. Expected number of RACH successes for different number of expected RACH arrivals.

be developed in the BTS to decide whether a given AGCH response should be provided using OSC or not. One possible solution for that problem would be to assign different training sequences depending on whether the MS supports OSC over signaling channels.

Performance may differ significantly depending on the number of TSCs available and UL receiver type. When two RACH bursts are received simultaneously, the probability of successfully receiving both with different TSCs is 50, 66.7 and 75% for 2, 3 and 4 TSCs respectively. Fig. 4 further illustrates the expected number of successfully received RACH blocks when OSC is used with different number of TSCs. In this figure, it is considered a Poisson process given by the average number of RACH arrivals, in which the expected RACH success is calculated as the probability of only one arrival, plus the probability of two arrivals with different TSC. Perfect radio conditions are considered, thus the errors are only given by multiple users transmitting RACH with the same TSC. The expected error in Fig. 4 thus shows that by using OSC and a higher number of TSCs we can increase significantly the RACH capacity, since it makes the signaling channel more robust for situations when users are trying to access RACH simultaneously.

The implementation of this technique only requires standardization of the broadcast procedure of the available TSCs. After the MS chooses the TSC to be applied in RACH, it continues the random access procedure as is currently done. It is expected that if this technique is used in real networks, the amount of MSs with support for the new training sequences increase gradually. In that case, the MSs supporting the new RACH TSCs probably will be able to access the network faster, which would avoid multiple RACH retransmissions and thus decrease the latency of legacy users as well.

III. Simulation assumptions

The results shown in this paper are based on a statistical analysis tool of the random access procedure for synchronous and asynchronous mixture of users [16]. It considers perfect radio conditions over one BCCH channel, and OSC is modeled by including the probability of two RACH messages arriving simultaneously with different TSCs. In case of more than two RACH bursts arriving in UL, an error is computed. When OSC is not used, the probability of successful RACH arrivals is calculated as the probability of only one arrival. Additionally, it is considered that, when using OSC, two AGCH responses can be transmitted simultaneously. A queue for the AGCH responses is determined by integrating the RACH successful attempts. If the AGCH queue would imply in a delay larger than the time expected for a RACH retransmission, a RACH error is computed. Apart from errors caused by collisions and large AGCH queues, no other errors are computed.

The traffic generation was considering 1000 asynchronous users, performing 5 accesses per hour. The number of synchronous users was varied as a simulation parameter. The traffic generation of synchronous users considers that all of them are starting within a 1s period, when they will start the random access procedure. This time spread is modeled by a beta distribution with parameters α and β described in Table I.

The random access procedure is modeled with a spread for each retransmission between 0 and $T-1$ TDMA frames. After each RACH failure, a new attempt is performed after S and $S+T-1$ TDMA frames. After M unsuccessful attempts, the MS should start cell reselection process before attempting the random access procedure again. The delay caused in this process is modeled by the timer T3146. All parameters related to the random access procedure are presented in Table I. A fixed AGCH capacity of approximately 25 responses per second is considered in the simulations, with a multiframe structure as shown in Fig. 5.

IV. Results

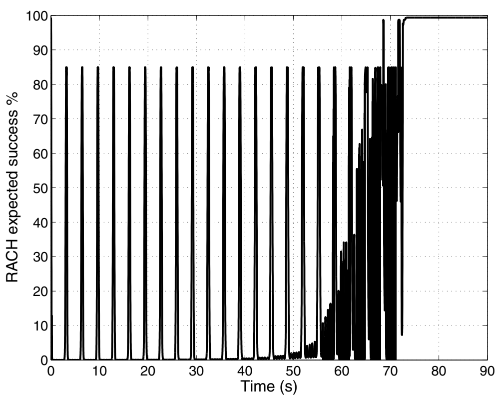
The simulation results with the time responses with and without OSC are shown in Fig. 6 for an extreme case with

TABLE I
SIMULATION PARAMETERS

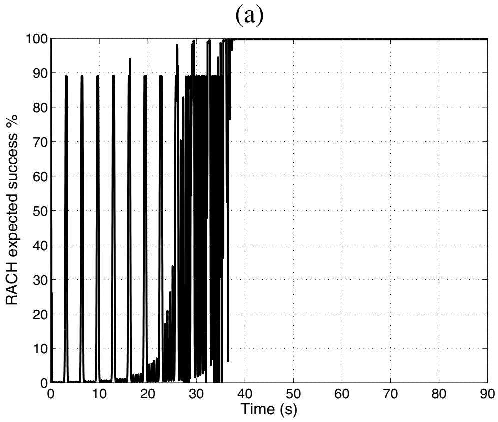
Label	Value/Unit	Label	Value/Unit
T	20 TDMA frames	N_{as}	1000 users
S	105 TDMA frames	λ_{u}	5 calls/user/h
M	4	α	3
T3146	1.1 s	β	4

Fig. 5. BCCH 51 multiframe configuration used in the model.

1000 users, where the expected RACH success is evaluated for all users present in the network. It is possible to observe that in the reference case without OSC in Fig. 6 (a), RACH success is nearly zero for an overload period of almost 75s. With exception of cell reselection periods of synchronous users, observed in peaks of 85% success, the expected success is lower than 1%. When the proposed method is applied as shown in Fig. 6 (b) this overload period is decreased to less than 40s. This is achieved by both increased RACH and AGCH capacity.



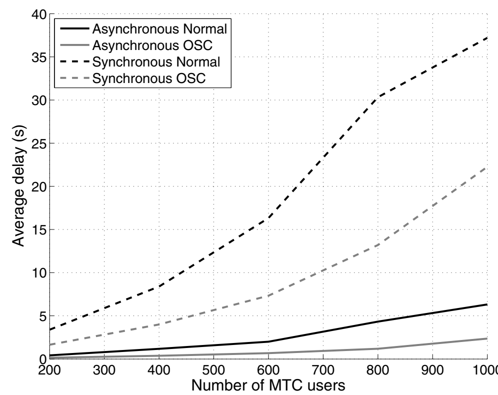
(a)



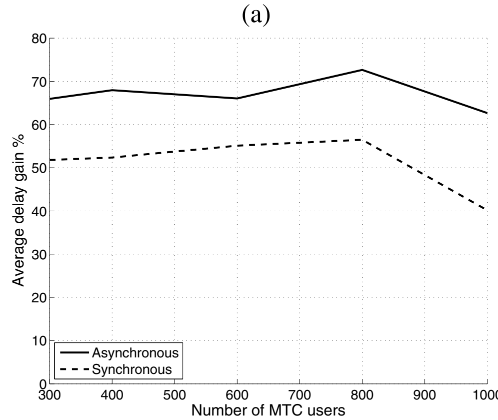
(b)

Fig. 6. RACH expected success evolution over time with 1000 normal asynchronous users and 1000 MTC synchronous users. (a) Reference case without OSC; (b) Improved signaling with OSC.

The results in Fig. 7 show the average access delay for a variable number of synchronized MTC users with and without using OSC. The average delays shown in Fig. 7 (a) are in general larger for synchronized users, which can reach 37s for a large number of MTC devices. For asynchronous users, average delays can reach 6s. It is possible to notice a significant improvement in access delay when OSC is implemented, especially when a large number of synchronous users are present. Fig. 7 (b) shows that asynchronous users have a reduction of 70% in the average delay, while this reduction is between 40-55% for synchronous users. For 400-700 users, the average access delay is decreased about 1.8-2.15 times.



(a)

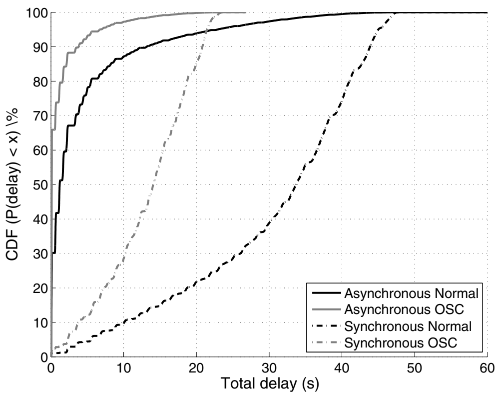


(b)

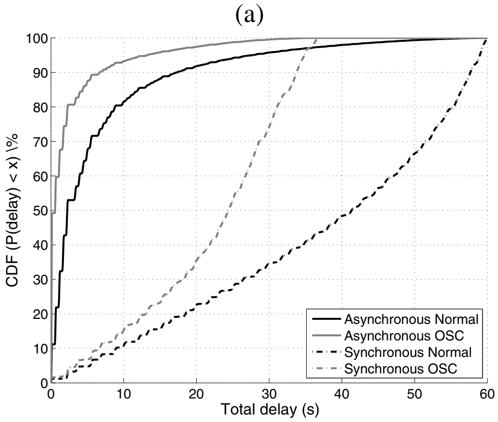
Fig. 7. Average access delay statistics for a mixture of synchronous and asynchronous users, with and without using OSC. (a) Absolute delay value; (b) Relative delay reduction with OSC.

The Cumulative distribution function (CDF) of the access delay with and without OSC for $N_s = 800$ and $N_s = 1000$ synchronous users is shown in Fig. 8. It indicates that the access delay for 10% of the asynchronous users in worst conditions is higher than 13.2s and 17.5s for 800 and 1000 users respectively. 90^{th} percentile is higher for synchronous users, which is 43.9s and 57.7s for 800 and 1000 users respectively. When OSC is applied over the access channels, this delay is reduced by 60–70% for most of the users, as the 90^{th} percentile of the delay of asynchronous users is 3.8s and 6.7s for 800 and 1000 MTC devices respectively. Conditions for synchronous users are also improved with OSC as the 90^{th}

percentile 20.82s and 33.8s for 800 and 1000 MTC devices, respectively.



(a)



(b)

Fig. 8. Cumulative density function of access procedure delay for (a) $N_s = 800$ and (b) $N_s = 1000$ synchronous users.

V. Conclusions

This paper has presented a solution for random access channels suffering from overload due to synchronous MTC users. The proposed technique combines the concept of Orthogonal sub-channels, in order to increase the signaling channels capacity without allocation of dedicated time slots for extra common control channels (CCCH).

Simulation results were obtained using a statistical tool in order to estimate the achievable gains with the proposed technique. Time domain responses have shown a large overload of CCCH channel for a large number of synchronous MTC devices. By applying the proposed technique, this overload period is decreased by 50%, which decreases the share of normal users that suffer extra delay when starting access procedure. Average delay statistics have shown significant improvement for both normal users and synchronized MTC users, with reductions between 50 and 70% in most of the cases. Additionally, analysis of the cumulative density function of access procedure delay showed large improvement for users with the worst access delays.

The results presented in this paper show that the proposed technique is able to improve significantly the overload situation caused by synchronous MTC devices. This is done by improving the robustness against collisions of RACH bursts in UL, enabling the detection of two users simultaneously. Additionally, it also improves capacity by increasing the number of immediate assignment responses in DL, which decreases the AGCH delay and avoids further RACH retransmissions.

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