Extended Simultaneous MAC-Packet Transmission in a CDMA Environment for Quality of Service Support

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Abstract

In this paper we want to introduce an extended Simultaneous MAC Packet Transmission (SMPT) approach that stabilises the quality of service (QoS) of a wireless Code Division Multiple Access (CDMA) system in terms of throughput, loss rate and delay. We apply these mechanisms to real time multimedia applications which suffer from the well known unstable properties of the wireless links. Different transmission methods with their influence on the QoS parameters are introduced and compared to common transmission methods. The suitability of our approaches is shown by observing its effects on typical QoS parameters of multimedia applications by using simulations.

Introduction

Simultaneously with the dramatic growth of cellular telephony an increasing demand for multimedia applications is notable. Until recently, multimedia protocols were designed for fixed networks. But the ongoing development of omnipresent mobile communication environment makes solutions necessary that are also suitable for mobile and wireless networks. Multimedia applications typically require stable throughput, small jitter, bounded delay and a bounded loss rate. In contrast to fixed networks the wireless link oscillates between good and bad states, i.e. may have temporary outage periods (see also [11]), where the conditions on the wireless link change dramatically.

From the application point of view a bad channel condition is recognised by a reduced throughput, higher loss rate, higher jitter and/or higher delay. Instead of attempting to live with the unstable service (e.g. adaptive applications [5]) we have introduced a mechanism, called Simultaneous MAC-Packet Transmission (SMPT) approach, in [1,2] that stabilises the service of a CDMA system by reducing the loss rate without increasing the jitter or delay. But further improvements in order to reduce the losses or the utilisation of the scarce spectrum can be found. The following paper analyse the improvements of the extended SMPT approach.

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The submitted paper is organised as follows: In chapter 1 we introduce the SMPT approach and the improvements that can be achieved in comparison to a common transmission method. In chapter 2 we apply SMPT to multimedia applications and develop variants of SMPT suitable for these applications. Chapter 3 describes our simulation environment and assumptions. Finally chapter 4 presents our simulation results.

1. Simultaneous MAC-Packet Transmission (SMPT) Approach

Now we give a brief introduction of the SMPT approach and assume a scenario where this approach can be implemented. This scenario consists of a CDMA based mobile communication system. CDMA systems generally leads to better utilisation of the bandwidth, which is shared among multiple users in contrast to other systems (FDMA/TDMA) where the bandwidth is assigned statically to the mobile terminal.

Figure 1: Simulation Model With SAR Entity And Bit Error Generator On The Wireless Link

Figure 1 depicts the application layer that passes segments, which results from a stream of transport units (like UDP or TCP segments), to the MAC layer, where the segment is divided into packets. These packets will be transmitted over the wireless link. Let us assume that a mobile is equipped with a number of k maximal codes. All k codes are assigned to the mobile immediately after the connection establishment. At the beginning of the transmission the mobile will use only one CDMA channel for a communication session. In this paper the term channel specifies a CDMA code that can be used for a
communication session. Then $B_{\text{good}}$ represents the bit rate for this initial CDMA channel in case of a good channel state. Using the simplest ARQ mechanism Send and Wait like it is discussed in [7] (see figure 2) and suggested in recent wireless LAN standards (e.g. IEEE 802.11) the usage of only one channel leads to the retransmission of erroneous packets in bad channel state while stored packets have to wait until the corrupted packet has been transmitted successfully.

The joint bit rate $B_i$ using $l$ ($l \leq k$) multiple CDMA channels of bit rate $B_{\text{bad}}$ in general is not exactly equal to the sum of the bit rates of all $l$ channels. With an increasing number of allocated channels the noise level will also increase resulting in a lower effective bit rate, because additional allocated CDMA channels disturb the other CDMA channels already in use. A degradation of a bit rate allocating $l$ CDMA channels is expressed by $\Delta_{\text{Codes},l}$ (see equation 1). The bit rate degradation $\Delta_{\text{Codes},l}$ was taken under consideration in the simulation model (see chapter 3). Therefore it as to be mentioned that using multiple channels has to be done under the consideration of the existence of other mobile terminals.

$$B_i = l \cdot B_{\text{bad}} - \Delta_{\text{Codes},l}$$

Equation 1: Resulting Bit Rate Using l Channels Simultaneously

**Physical Restriction**

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$$B_i = l \cdot B_{\text{bad}} - \Delta_{\text{Codes},l}$$

Equation 1: Resulting Bit Rate Using l Channels Simultaneously

2. Extended SMPT for Multimedia Applications

In contrast to common data services (FTP, WWW, email) multimedia applications have higher requirements on the QoS parameters. Particularly the jitter of application segments has to be bounded. Only by using SMPT a stabilisation of the segment jitter can be achieved. Therefore the number of retransmissions (that have to be done in the dimension of time) of MAC packets belonging to one application segment has to be limited. If the number of retransmission is exceeded the segment is lost. The goal of our approach is to reduce these losses.

**SMPT with limited number of codes**

Assuming that we have a given jitter bound $\beta$ and in addition to this for the SMPT approach a limitation of $k$ maximum usable codes, figure 12 shows the influence of the error characteristic on the physical link for the sequential transmission and SMPT. As an example a segment was divided into 13 packets. Thus the time to send the whole segment in case of no errors on the wireless link is given by $\alpha$. When all the packets of one segment can not...
be transmitted within a transmission window \( TW = \alpha + \beta \) the whole segment will be discarded.

In the sequential case every retransmission increases the segment delay. This was reflected by \( \Phi \), which represents the number of retransmission in the sequential case. If equation 2 is fulfilled (the influenced jitter \( J_{\text{sequential}} \) is smaller than the required bounded jitter), the sender-side MAC will proceed to transmitted the packets in the sequential case. Equation 3 do this for the SMPT approach.

\[
J_{\text{sequential}} = \sum_{i=1}^{\infty} \Phi_i \leq \beta
\]

*Equation 2: Influenced Jitter By The Total Number Of Retransmissions Using The Sequential Transmission Method*

\[
J_{\text{SMPT}} = \sum_{i=1}^{\infty} \gamma_i \leq \beta
\]

*Equation 3: Influenced Jitter By The Total Number Of Retransmissions Using SMPT*

Figure 12 shows an error burst of length 5 at the beginning of the transmission. The impact of the delay using a maximum number of usable \( k=4 \) codes is only \( \gamma_i=2 \) (instead of \( \Phi_i=5 \) for the sequential case). By increasing the number of allowed used codes \( k \) furthermore the influence on the jitter can be further reduced. The influence on the segment jitter was taken under consideration by \( \gamma_i \). Figure 12 shows that \( \gamma_i \) increases in the condition that the number of used codes equals the limit \( L_{\text{limit}} \) and an error on the wireless link occurs (e.g. \( t=4,5,11,16,17,18 \)). The limit \( L_{\text{limit}} \) can be described as followed (see also figure 12):

\[
L_{\text{limit}} = \begin{cases} 
  h = \sum_{i=1}^{\infty} \gamma_i : & t \leq \alpha \\
  k : & \alpha \leq t \leq \alpha + \beta : h < k \\
  k : & \alpha \leq t \leq \alpha + \beta : h \geq k 
\end{cases}
\]

*Equation 4: Calculation Of \( L_{\text{limit}} \) Under Consideration Of \( \alpha \) And \( \beta \)*

\( h \) describes the number of stored packets in the queue that are left to be transmitted. While the sum of \( \gamma_i \) over all error burst \( i \) does not exceed \( \beta \) the sender MAC will proceed to transmit MAC packets. If equation 3 for the SMPT approach with a code limitation \( k \) and a bounded jitter \( \beta \) and equation 2 for the sequential approach is fulfilled, the sender will go on to transmit the MAC packets of one segment.

Self Healing SH-SMPT

In combination with SMPT a new mechanism called **Self Healing** is introduced. The mechanism shall reduce the influenced jitter using the possibility to send on additional channels. Considering the situation that after an error burst the channel becomes *good* again and the jitter was influenced negatively. With the continuing usage of the multiple channels we can try to decrease the affected jitter \( J_{\text{SMPT}} \) by sending \( h \) \((h \leq (k-1)\) per time slot) packets in parallel until the influence on the jitter \( J_{\text{SMPT}} \) becomes zero. Figure 5 depicts how this approach works: After an error burst with a duration time of five, the packets 1,2,3 and 4 are send successfully on parallel channels at moment 6. The jitter \( J_{\text{SMPT}} \) equals two. Now with the **Self Healing** method \( h=2 \) packets (packet number 6 and 8) are send on parallel channels within the Self Healing Phase \( \text{SH}_1 \). In contrast to the pure SMPT, additional channels will be used also to repair the jitter. Especially for segments consisting of a high number of packets this approach will lead to better results.

**Figure 5: Self Healing Transmission Method For An Influenced Jitter Of Two**

For SMPT with Self Healing the equation 3 has to be rewritten:

\[
J_{\text{SMPT}} = \sum_{i=1}^{\infty} \gamma_i - \sum_{i=1}^{\infty} \text{SH}_i \cdot h \leq \beta
\]

*Equation 5: Influenced Jitter by the total number of retransmissions using SMPT and Self Healing*

Slow Start SL-SMPT

A very important point of investigation is how will the additional codes influence the capacity of the whole system. Obviously a higher number of channels lead to a decreasing Signal to Noise Ratio (SNR) and therefore reducing the number of used channels will have positive effects. In figure 6 such an example is depicted. The corrupted packet number one will be repeated until it will be transmitted successfully. Sending this kind of probing packets and further improvements was fully described in [14]. The probing packets can be send every \( t \) time slots. A higher value of \( t \) will lead to improvements for power saving, but within this work we will check out the channel state by sending every time slot a packet \((t=1)\). In the error phase
reacts like the sequential transmission method and the jitter is influenced by $\gamma$. After a successful transmission the jitter will be adjusted by sending in parallel (packet number 3,4,5,7,8) under the use of the Self Healing approach.

We expect that this mechanism has great advantages for bursty error characteristics on the wireless link. Improvements that can be achieved for power saving are mentioned in [14] but are beyond the scope of this paper. If we further assume that a group of users has the same channel characteristic and we want to have a degradation on the influence by sending in parallel, a further improvement is possibly that mobiles can start the Self Healing process after a certain back-off time.

We have developed a simulation model shown in figure 4 using PTOLEMY [4]. Considering figure 1 the application layer generates segments with a fixed length L. These segments are generated with a constant rate. The MAC layer divides the segments into N packets. To each packet an header/trailer $\zeta$ is added. The header is added to identify MAC packets in the right order and to assign the MAC packets to the appropriate segment. In addition to that redundancy is added to detect corrupted packets. The frame, which is composed by one packet and the header/trailer $\zeta$ is called a MAC Packet Data Unit (MPDU). The length of a MPDU is denoted as $L_{\text{MPDU}}$. All MPDUs are stored in an infinite queue and will be sent over the wireless link. The scenario include an Additive White Gaussian Noise (AWGN) channel using Binary Phase Shift Keying (BPSK). We assume that only one bit error within one time slot corrupts all MPDUs currently transmitted on the wireless link. To generate bit errors we used a multi-layered two state Markov chain. As depicted in figure 7 in we start the simulation model at one stable operation point $P(1,1)$ with a total number of b background channels.

![Figure 6: Slow Start Transmission Method For An Influenced Jitter Of Two](image6.png)

3. Simulation Model

We have developed a simulation model shown in figure 4 using PTOLEMY [4]. Considering figure 1 the application layer generates segments with a fixed length L. These segments are generated with a constant rate. The MAC layer divides the segments into N packets. To each packet an header/trailer $\zeta$ is added. The header is added to identify MAC packets in the right order and to assign the MAC packets to the appropriate segment. In addition to that redundancy is added to detect corrupted packets. The frame, which is composed by one packet and the header/trailer $\zeta$ is called a MAC Packet Data Unit (MPDU). The length of a MPDU is denoted as $L_{\text{MPDU}}$. All MPDUs are stored in an infinite queue and will be sent over the wireless link. The scenario include an Additive White Gaussian Noise (AWGN) channel using Binary Phase Shift Keying (BPSK). We assume that only one bit error within one time slot corrupts all MPDUs currently transmitted on the wireless link. To generate bit errors we used a multi-layered two state Markov chain. As depicted in figure 7 in we start the simulation model at one stable operation point $P(1,1)$ with a total number of b background channels.

![Figure 7: Multilayered Two State Markov Chain For One Stable Operation Point With N Additional Channels And The Resulting Bit Error Rate](image7.png)

Equation 6: Calculation Of The Bit Error Probability For An AWGN Channel

For all simulations, we used parameter values given in table 1.

<table>
<thead>
<tr>
<th>Application</th>
<th>L</th>
<th>530 byte</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAC</td>
<td>$L_{\text{MPDU}}$</td>
<td>106 bit</td>
</tr>
<tr>
<td></td>
<td>$\zeta$</td>
<td>40 bit</td>
</tr>
<tr>
<td>$\beta[1/\text{MPDU}]$</td>
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<td></td>
</tr>
<tr>
<td>k</td>
<td>2.3</td>
<td></td>
</tr>
<tr>
<td>number of background channels</td>
<td>15-45</td>
<td></td>
</tr>
<tr>
<td>Channel</td>
<td>$N_{\text{spreading}}$</td>
<td>128</td>
</tr>
<tr>
<td></td>
<td>$p$</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>$P_{\text{Good}}$</td>
<td>0.99</td>
</tr>
<tr>
<td></td>
<td>$P_{\text{Bad}}$</td>
<td>0.01</td>
</tr>
</tbody>
</table>

Table 1: Simulation Parameters

4. Performance Evaluation

In order to achieve a feeling how the extended SMPT approaches can improve the QoS parameters, we present simulation results for the algorithms described in chapter 3 and the sequential case. We show how SMPT in
combination with **Self Healing** and **Slow Start** reduces the packet loss rate compared to the sequential case.

**Self Healing SH-SMPT**

In case we use the Self Healing method in combination with the pure SMPT the results are depicted in figure 8. The figure shows the Segment Loss Probability (SLP) versus the number of active channels in one wireless cell. The sequential transmission method leads to a high loss probability also with a moderate number of active channels. For SMPT transmission method the extended **Self Healing** method leads always to better results using the same maximal number of channels. But the influence of **Self Healing** method decrease for higher number of maximal channels. E.g. using three maximal codes lead to a smaller gain than with only two channels. The higher the number of maximal channels the less the gain on the SLP.

![Figure 8: Segment Loss Probability (SLP) Versus Number Of Background Channels [15-45] With A Bounded Jitter Of Two And Three For An AWGN Channel](image)

But the better SLP has to be paid with an higher usage of the spectrum. Figure 9 depicts the mean number of used channels per time slot. Obviously the sequential transmission method has only one channel in use, while the SMPT methods will use more of the channels. Furthermore the Self Healing algorithm has an increased usage of channels compared to the pure SMPT approach.

![Figure 9: Mean Number Of Used Codes Per Time Slot Versus Number Of Background Channels [15-45] With A Bounded Jitter Of Two And Three For An AWGN Channel](image)

**Slow Start SL-SMPT**

In figure 10 the Segment Loss Probability versus the number of active background channels is shown for the *Slow Start* transmission method in comparison to the sequential and the pure SMPT approach. It can be shown that the *Slow Start* approach leads to a slight worse loss probability than the pure SMPT approach.

![Figure 10: Segment Loss Probability (SLP) Versus Number Of Background Channels [15-45] With A Bounded Jitter Of Three For An AWGN Channel](image)

But the advantage of the *Slow Start* approach is the smaller number of used codes per time slot. This is depicted in figure 11. Thus more multiple mobile terminals within one wireless cell can be handled.

![Figure 11: Mean Number Of Used Codes Per Time Slot Versus Number Of Background Channels [15-45] With A Bounded Jitter Of Three For An AWGN Channel](image)

**Conclusion**

In summary we have worked out two extended mechanism in combination with pure SMPT to support multimedia applications, which require a bounded jitter and a stable throughput. We presented simulation results showing that both mechanisms lead to smaller segment loss probabilities.
compared to the sequential transmission method. The Self Healing transmission method achieve the lowest SLP using a major part of the spectrum. A more moderate use of spectrum is done by the Slow Start method. On the other hand this method leads to a higher SLP.

To achieve a high number of mobile users and support them with high QoS parameters both methods can be used by the mobile users. Therefore a centralised unit is needed (e.g. base station) that will assign each user its appropriate transmission method (sequential/pureSMPT/SH-SMPT/SL-SMPT) to support the required QoS parameters. It is also possible to use combinations of the different approaches (e.g. for long segments to start with the sequential method and to finish with the SH SMPT method).


[F5] Dorgham Sisalem): "End-To-End Quality of Service Control Using Adaptive Applications", IFIP Fifth International Workshop on Quality of Service IWQOS ’97, New York, USA, IFIP WG 6.1 , May 1997


Figure 12: Pure SMPT Transmission Method For Multimedia Applications