A QOS-AWARE RESOURCE REQUEST MECHANISM FOR DELAY SENSITIVE SERVICES OVER TDMA/TDD WIRELESS NETWORKS*

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Keywords: Resource Request, QoS, Wireless LAN, HIPERLAN/2, Delay Sensitive Traffic.

Abstract: Recent advances on wireless technology are enabling the design and deployment of multiservice wireless networks. In order to be able to meet the QoS requirements of various applications, it is essential to deploy QoS provisioning mechanisms. In this paper, we propose a QoS provisioning mechanism for providing support to time constrained applications over wireless networks. The proposed mechanism is developed using a signaling procedure. Our simulation results show the effectiveness of the proposed mechanism when supporting time constrained services, such as MPEG-4 video communications.

1 INTRODUCTION

Nowadays wireless local networks represent an alternative to wired LAN's. Current wireless LAN's operate at transmission rates able to support various types of applications, such as, data, voice and video. However, one of the main open issues is the definition of QoS mechanisms capable of meeting the QoS requirements of the various applications. Within a broadcast environment, such as a wireless LAN, it is important to properly allocate the bandwidth to the various applications. Even though, recent standards have the underlying elements to carry this important task, they fall short on the definition of all the mechanisms required to implement a whole structured set of mechanisms. In this paper, taken as a basis the HIPERLAN/2 standard (H/2, 2000), we define a resource request mechanism capable of meeting the QoS requirements of time-sensitive applications.

The article is organized as follows. Section 2 provides a short overview of the HIPERLAN/2 standard. In Section 3, we review the related bibliography on the area of MAC algorithms for TDMA/TDD wireless networks. Our proposed resource allocation mechanism is described in Section 4. The results of a performance evaluation study via simulation are given in Section 5. Finally, Section 6 concludes the paper.

2 HIPERLAN/2 MAC PROTOCOL

The HIPERLAN/2 MAC protocol (H/2, 2000) is based on a dynamic TDMA/TDD scheme with centralized control, using as logical transmission unit frames of 2 *ms*. Given that the allocation of the frame resources to each Mobile Terminal (MT) is made by the Access Point (AP), the requirements of the application resources have to be known of these entities, which are responsible of allocating the available resources according to the user needs. Towards this end, each MT has to request to the AP the required resources by issuing a *Resource Request (RR)* message, while the AP informs the MT of the positive outcome by using a *Resource Grant (RG)* message. The connections are identified by two identifiers: MAC_ID and DLCC_ID. A MAC_ID is assigned to each MT at association time, while a DLCC_ID is assigned to each connection when this latter is setup; both identifiers are assigned by the AP.

Figure 1 shows the format of the transmission frame defined by the HIPERLAN/2 standard for a system operating under the infrastructure mode. The frame is divided into four phases, each phase being composed by a group of transport channels. A transport channel is a logical entity and its classification depends on the type of data that it conveys.

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*This work was supported by the Ministry of Science and Technology of Spain under CICYT project TIC2003-08154-C06-02 and the Council of Science and Technology of Castilla-La Mancha under project PBC-03-001.

M. Delicado F., Cuenca P. and Orozco-Barbosa L. (2004).
A QOS-AWARE RESOURCE REQUEST MECHANISM FOR DELAY SENSITIVE SERVICES OVER TDMA/TDD WIRELESS NETWORKS.
In *Proceedings of the First International Conference on E-Business and Telecommunication Networks*, pages 402-409
DOI: 10.5220/0001403604020409

The phases of a frame are:

1. *Broadcast phase*: this phase is used for the communications taking place on the downlink. It is formed by a preamble to determine the beginning of the frame and three transport channels:
    - *BCH*: contains the configuration parameters of the frame, such as the number of RCH channels, the size of the preambles of the uplink phase and RA, among others.
    - *FCH*: its size is variable and includes the resource grant (RG) messages for each connection. These messages specify the number of granted transport channels and their position within the frame.
    - *ACH*: contains the information regarding the number of collisions having occurred in the RA phase of the previous frame.
2. *Downlink phase*: this phase is formed by a group of downlink PDU trains, which are formed by a preamble and a variable number of SCH and LCH channels dedicated to each one of those connections with resources granted in the FCH. The SCH channels convey error control codes as well as information on any change on the connection parameters. The LCH channels transport user data, represented as PDU trains in Figure 1. Each PDU train conveys the data pertaining to various connections associated to a single MAC_ID.
3. *Uplink phase*: similar to the downlink phase, this phase is also formed by Uplink PDU trains, separate one from another by a guard time, and composed by a preamble and a variable number of SCH and LCH channels dedicated to each one of the connections. The SCH channels convey resource request messages control codes or other control messages. The LCH channels transport user data, represented as PDU trains in Figure 1. Each PDU train conveys the data pertaining to various connections associated to a single MAC_ID.
4. *Random Access (RA) phase*: consists of the number of RCH channels determined in the BCH channel, the minimum number of RCH channels in each frame should be one. Each RCH channel is inserted in a RCH PDU which is formed by a preamble and a RCH channel. It is used for the transmission of control information, provided that the MT does not have granted resources in the UL phase, or during the beginning of the association process. Each RCH PDU is separated from the previous one by a guard time. A contention process based on a Slotted-ALOHA scheme is used to access the RCH channels.

It is important to note that not all of the transport channels have the same size and that this one depends on the channel type. This is also true for the preambles and guard times whose sizes are specified, at the beginning of the frame, in the BCH channel (H/2, 2000).

3 RELATED WORK

Given the central role played by the MAC algorithms on enabling the provisioning of the QoS requirements to the various applications, there has been a large number of studies focusing on the design and evaluation of QoS-aware MAC protocols. In (Karol et al., 1995), the authors describe a resource reservation protocol. In this protocol, the MTs initially issue a resource request message by using a contention-based protocol, similar to Slotted-ALOHA. Once having been allocated a number of slots, the data packets convey, via “piggybacking’, the following MT’s resource requests. As soon as the MT becomes idle, the resources are freed. At a latter time, when the MT becomes once again active, this one has to start the reservation process by issuing a first request via the contention process.

The MASCARA algorithm introduced in (Passas et al., 1997) makes use of a resource request mechanism similar to the one described in (Karol et al., 1995). The mechanism makes use of a “scheduler” based on a “token bucket” scheme to distribute the resources among the active connections.

More recent works focusing on the HIPERLAN/2 standards (Kadelka and Masella, 2001), (Politis and Tafazolli, 2002), have proposed several algorithms to distribute the bandwidth resources to different types of connections. Within a given type of connection, the bandwidth is allocated by taking into account the status of the buffers or the connection parameters provided at the time of establishing the connections. However, the authors do not specify the resource request (signaling) protocol.

In (Lenzini and Mingozzi, 2001) the authors introduce an allocation algorithm based on a FIFO policy and a signaling protocol. The proposed allocation algorithm allocates a fixed number of control channels, whose associated connection can use to further request more resources (bandwidth).

One of the main drawbacks of the request mechanisms proposed by the authors in (Karol et al., 1995) and (Passas et al., 1997) is that they have been built around a contention-based MAC. It is well known that the performance of these mechanisms severely degrades as the number of active connection increases. This makes the allocation mechanism prone to delay and losses; an undesirable condition when developing QoS mechanisms. Furthermore, the “piggybacking” mechanism can not be implemented in HIPERLAN/2.

One option is to replace it by a "polling" mechanism, or by making use of a fixed number of control channels as proposed in (Lenzini and Mingozzi, 2001). The drawback of the latter approach is the excessive overhead introduced as the number of uplink connections increases.

4 A NOVEL RESOURCE REQUEST MECHANISM

One of our main design objectives has been the definition of an effective signaling protocol. The effectiveness of such mechanism will depend on the amount of overhead: number of control packets and retransmissions required by the unsuccessful transmission attempts due to the use of the contention-based mechanism.

The algorithm works in the following way. The AP starts by polling the MT as soon as a connection is set up. The MT replies to the AP's polling by specifying the amount of required resources. Based on the number of resource requests received, the AP will grant the requested resources to the requesting MTs. Depending on the network operating conditions, it may take several frames for the AP to completely grant all the requested resources (LCHs). As soon as the AP finishes granting the requested LCHs to a given MT, the AP reserves a SCH for that MT. The MT can then use this SCH channel to reply to the AP's polling.

Figure 2 depicts the process used by this type of connection. Figure 2.(a) shows the operation of the polling mechanism implemented by the AP. The AP starts by issuing a RG message, RG:#SCH=1, conveyed via an SCH channel to poll the MT. The MT replies by a RR message requesting *n* LCH channels, RR:#LCH=*n*. It is then assumed that the AP grants *i* slots in a first reply (RG) and the remaining *n-i* requested resources in a second reply (RG:#SCH = 1, #LCH = *n-i*). In this second RG, the AP also allocates an SCH to the MT, the MT can use this SCH to place its next resource request (RR) message.

Figure 2.(b) shows the case when the AP having polled the MT issues a second polling message, RG:#SCH = 1, after its timer has expired out. Furthermore, in the case depicted, it is assumed that the MT has been unable to grant the resources requested in the first request issued by the MT. This condition may arise when due to a long backlog, the AP is unable to serve the request due to the lack of available resources. In this case, after a timeout period, the AP polls once again the MT.

By basing the mode of operation of the request mechanism on a "polling" scheme we look to address two main issues: 1) to minimize the number of control packets (overhead) required to convey the MT's requests to the AP; 2) to avoid the use of a contention procedure, which under heavy load conditions may result on excessive delays or even on an unstable operation of the allocation scheme. It is evident that the effectiveness of the overall control structure to meet the QoS requirements will depend very much on how the different elements cooperate. Under the proposed architecture, it is required that the entity responsible of allocating the resources counts with the most up-to-date information on the status of the all the active MTs. The use of a proper tuned-up polling mechanism should prove more effective on distributing the bandwidth among the active MTs by taking into account their level of activity. In fact, the polling mechanism can be further enhanced to fairly distribute the bandwidth according to the policies on place in a given setup.

Under the proposed scenario, we assume that the AP will serve the MTs requests on a strictly first-in first-out (FIFO) discipline. This will allow us to carry out a comparative study of our proposed scheme with some other schemes proposed in the literature. Our future plans include the study of different scheduling disciplines to supplement the signalling mechanism.

5 PERFORMANCE EVALUATION

The main objective of this performance evaluation is to assess the behavior of the proposed resource request mechanism with variable bit rate traffic and delay sensitive applications. In our study we use one HIPERLAN/2 cell operating in centralized mode. We suppose that the connections have already been established, i.e., it is assumed that all MTs and associated connections are already engaged in the transmission of video data. The only control messages are those required to request and grant resources, RR and RG messages, respectively. Furthermore, we assume the use of use short preambles, times of guard of 2 *ms*, and that the physical modes for the SCH and LCH channels are QPSK3/4 and 16QAM3/4, respectively.

Regarding the applications each MT supports two applications of MPEG-4 video ((MPEG4, 1999)) one in the downlink and another in the uplink. Each video application begins to transmit within a random period given by the expression $t = uniform(0, \frac{12}{f})$ being f the frame rate. In this way, the peak periods of the source rates are randomly distributed along a GOP period. The transmission of a video frame is uniformly distributed along the interval of duration of a frame ($\frac{1}{f}$). We use a sequence in QCIF format at 25 frames/sec of the movie Mr. BEAN (Fitzek and Reisslein, 2001). Figure 3 shows a snapshot of the traffic generated by the MPEG-4 video sources. It is clear from this figure that these sources exhibit a high degree of burstiness characterized by a periodic traffic pattern and a high variance on the rates at which the data is generated.

The model of HIPERLAN/2 network has been implemented in OPNET 9.0 (OPNET, 1987-2002). We have measured the jitter among video frames, i.e., the time between the last packets of two consecutive frames and the end-to-end delay for each packet. In order to limit the delay experienced by the video application, an essential condition to guarantee the QoS required by the video application, the maximum time that a piece of video data (referred form now on as packet) can remain in the transmission buffer has been set to 100 *ms*. This time limit is on-line with the values specified in (Karam and Tobagi, 2000).

In order to evaluate the proposed mechanism, referred from now on as *PROP*, we carry out a comparative study of our proposed scheme with two schemes proposed in (Lenzini and Mingozzi, 2001). The first method therein, referred from now on as *MING1* reserves a given number of LCH channels and one SCH channel every given number of frames. In this way, the MT counts at regular intervals with a given number of LCH channels for data transmission. The MT uses the SCH channel to request for more resources on a timely basis. The second method in (Lenzini and Mingozzi, 2001), namely *MING2*, only reserves one SCH channel every given number of frames. It is clear that the performance of all three mechanism heavily relies on parameters, such as the number of reserved LCH and SCH channels, the frequency at which the MT´s can place the resource request (RR) messages and the timer used by the polling mechanism. We start then by studying the performance of the *MING1* and *MING2* schemes by tuning their system parameters when supporting the video services under consideration. This will set the basis for a fair comparative study.

Figure 4.(a) shows the end-to-end delay as a function of the number for the MING1 scheme. We have varied the number of reserved LCHs per frame as well as the reservation period of the SCH channel. This last parameter has been expressed as $\frac{\#SCH}{\#frames}$. From the figure, it is clear that the system performance is severely affected as the number of reserved LCHs is increased. This is due to the fact that this scheme is unable to statistically multiplex the traffic. This is particular important in a system supporting video traffic. This traffic is characterized by a high variability. This is clearly shown by the fact that when LCH=4, the maximum number of MTs is six while for LCH=2, the maximum number MTs reaches 12. From the figures, it is also clear that by varying the reservation period of the SCH does not help when the system operates under heavy load. On the contrary, under low loads, the periodicity of the SCH has a clear impact on the system performance. From the figure, a clear example is provided for the system consisting of 6 MTs and making use of 2 LCHs.

Figures 4.(a) and (b) show that the best results are obtained for the system with the least number of reserved LCHs and lowest ratio of SCH per frame. It is important to note that the number of LCHs (LCHs=2) is given by the average bitrate required by the video sequence.

In the case of the MING2, no reservation of LCHs whatsoever is made. However, the AP changes the rate at which the SCH is assigned to the MTs. Figure 5.(a) shows the end-to-end delay. This scheme exhibits similar performance to the one obtained for the MING1 scheme. At low loads, the performance on the system improves as the frequency at which the SCH´s are provided to the MT´s is increased. This is due to the fact that the MTs can more frequently place their requests. It is clear that under these load conditions, there are plenty of available resources to fulfill the MT's requirements. However at high load conditions, (#MT $\geq$ 15), the system shows better results as the SCHs are granted at a lower rate. Once again, this can be explained to the decrease in the multiplexing gain due to the resources granted to the connections. As more resources are reserved, the frequency of the control slots (to convey the MT's requests) should be made less frequent to free resources that can be effectively used for data transmission.

Regarding the jitter, the MING2 exhibits the best results for the cases when the SCHs are granted at the lowest rate (longest period), see Figure 5.(b).

In the case of the PROP mechanism, Figure 6.(a) shows the end-to-end delay. From the figure, it is clear that the best results are obtained when the timer is set to 0.04 *s*. This can be explained by the fact that for a shorter timer period, more capacity is used to the SCHs resulting in a reduction of available capacity dedicated to data transmission (LCHs). In the case of low loads, the performance is independent of the value of the timer; since the system is able to promptly fulfill the MT´s needs. In other words, the system is able to promptly poll the stations, i.e., before the expiration of the timer.

Figure 6.(b) shows the jitter for the PROP mechanism. From the figure, it is clear that the best results are obtained for the case when the timer has been set to 0.04 *s*.

In order to make a fair comparison, we have taken the system configurations exhibiting the best results for all three schemes. For the case of MING1, LCH=2, and a SCH every 15 frames. Similarly to MING1, for MING2, one SCH channel every 15 frames. In the case of PROP, the timer has been set to 0.04 *s*.

Figures 7.(a) and 7.(b) show the end-to-end delay and jitter for all three schemes, respectively. From the figures, it is clear that our proposed mechanism exhibits the best results. As shown in the figures, the MING1 schemes is unable to provide support to more than twelve stations due to the fact that this scheme is unable to statistically assign LCH to the active connections. In particular, it is important to note that under low loads, our mechanism ensures a shorter delay on the transmissions taking place over the downlink.

Figures 8 show the packet losses as a function of active MTs. The losses reported in this figure corresponds to those PDU having resided in the MT's transmission buffers for more than 100 *ms*. As seen from the figures, our proposed scheme exhibits good results. The figures also show that the inability of the MING1 scheme to provide lossless transmission even to a system consisting of as few as eight MTs.

6 CONCLUSIONS AND FUTURE WORK

In this paper a novel resource request algorithm for HIPERLAN/2 has been developed and evaluated. We have evaluated the proposed scheme and conducted a comparative study with two other schemes previously proposed in the literature. We have been particularly interested in examining the ability of the proposed scheme in supporting MPEG-4-based services. Our results have shown that the proposed scheme is able to support a larger number of connections than a scheme based on the static reservation of a minimum number of slots. Furthermore, we have shown that proposed scheme exhibits a shorter end-to-end delay under all network loads. We plan to conduct further studies under a multi-service scenario, i.e., when various services, such as video, voice and data are multiplexed together over the same wireless channel. As already mentioned, we will also consider to supplement the proposed signalling mechanism with a scheduling policy.

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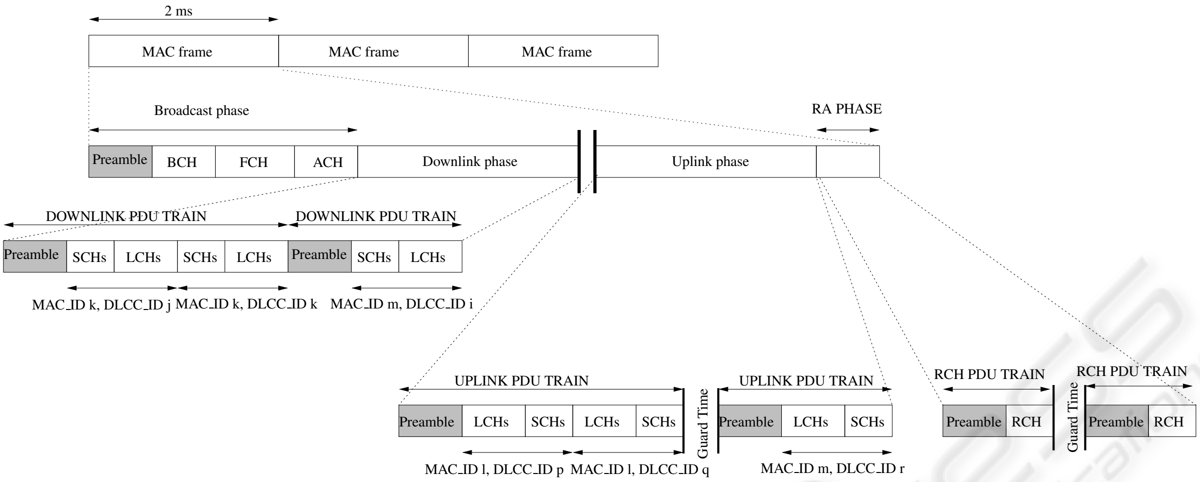
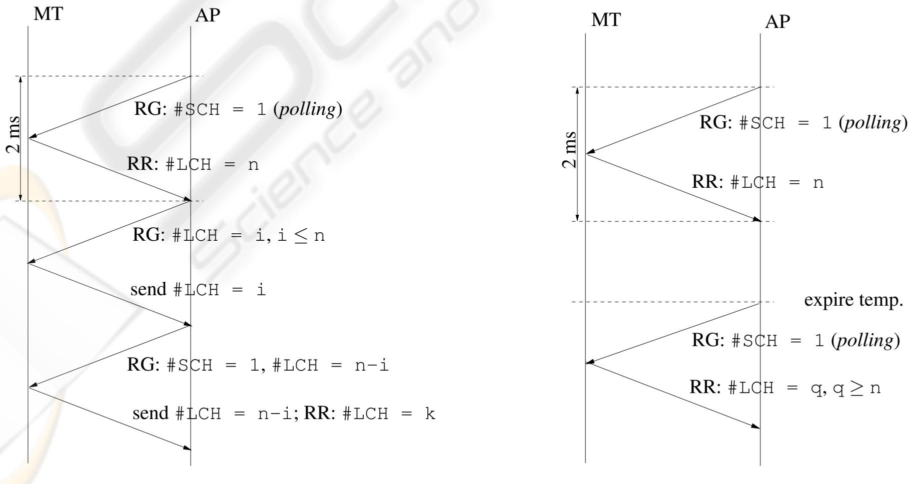


Figure 1: HIPERLAN/2 MAC frame format



(a)

(b)

Figure 2: Resource request Mechanism

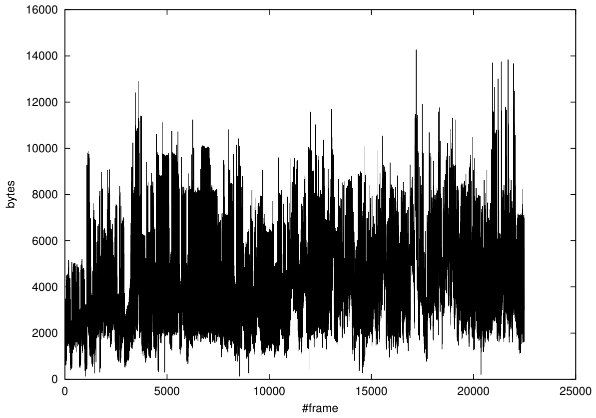
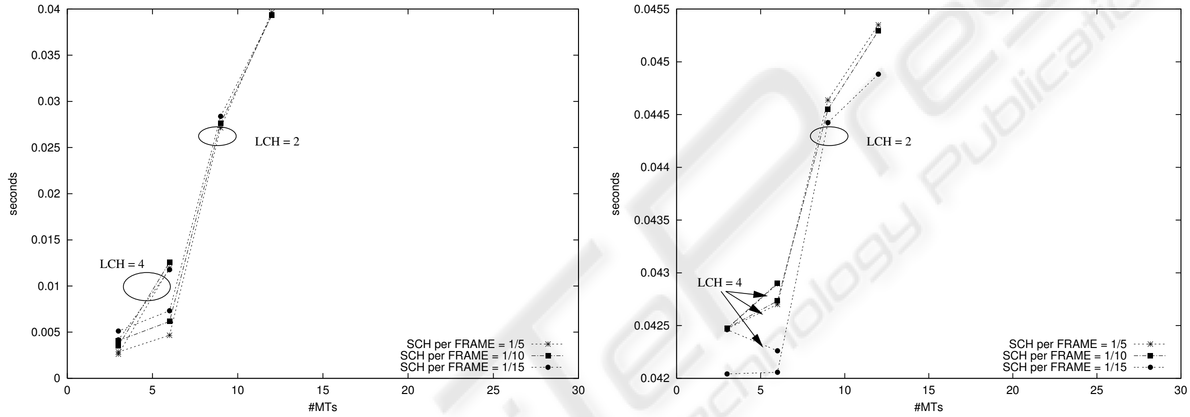


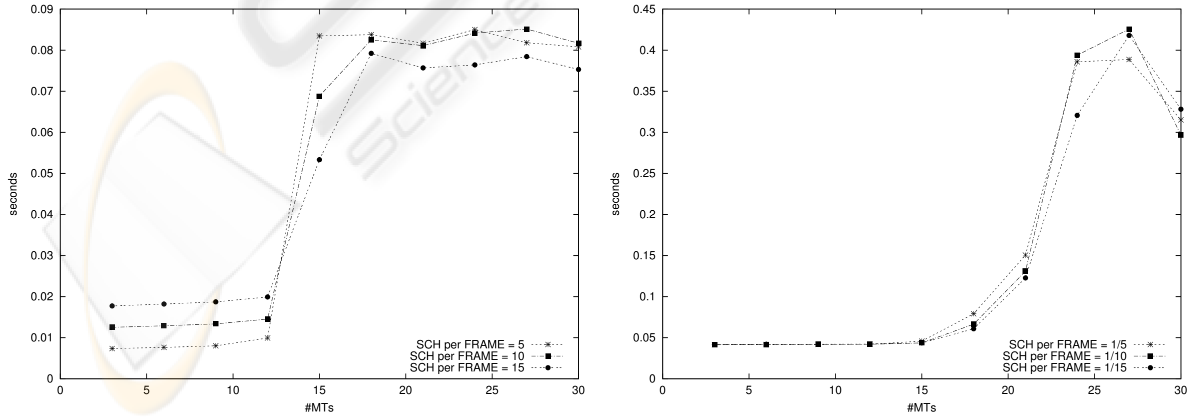
Figure 3: MPEG-4 stream



(a) Delay vs. #MTs

(b) Jitter vs. #MTs

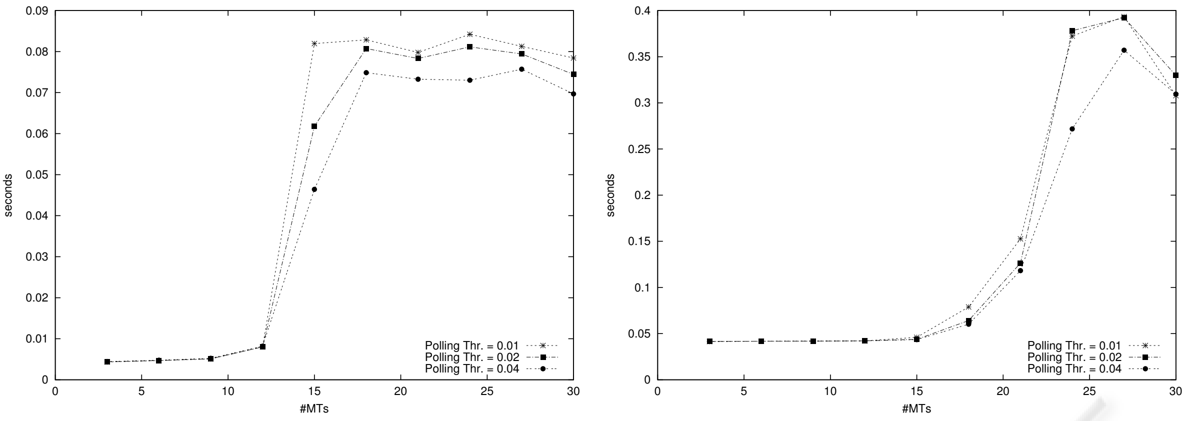
Figure 4: Delay and Jitter - MING1 mechanism



(a) End-to-End delay vs. #MTs

(b) Jitter vs. #MTs

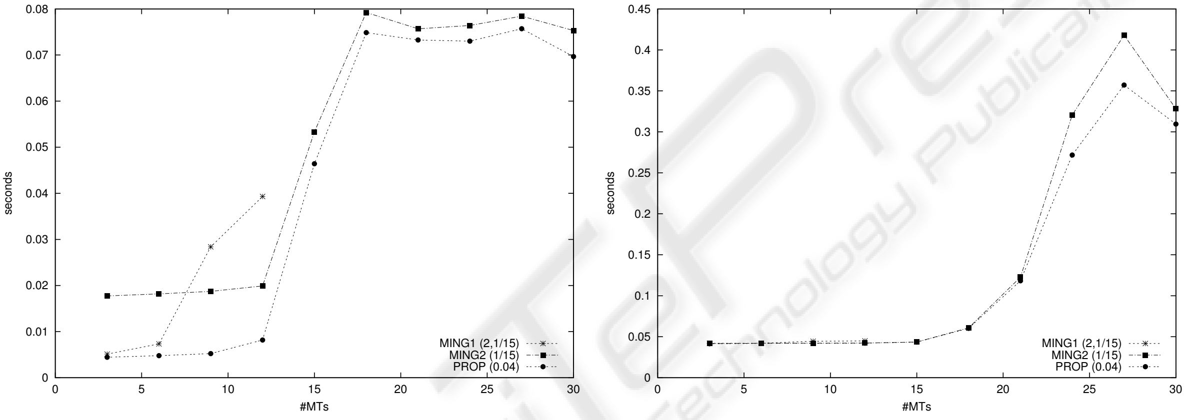
Figure 5: Delay and Jitter - MING2 mechanism



(a) End-to-End delay vs. #MTs

(b) Jitter vs. #MTs

Figure 6: Delay - PROP mechanism



(a) End-to-End delay vs. #MTs

(b) Jitter vs. #MTs

Figure 7: Delay and Jitter- all mechanisms

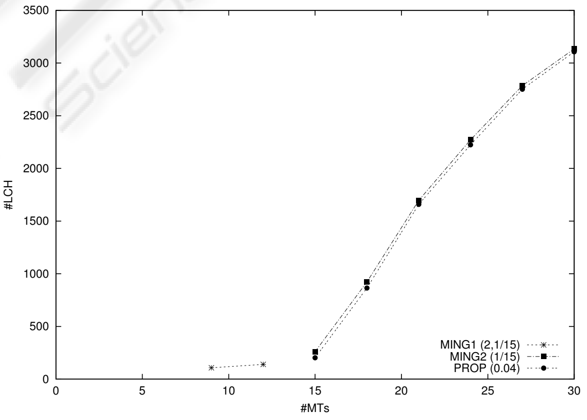


Figure 8: Packets Losses - all mechanisms