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VTT, Vuorimiehentie 5, PL 2000, 02044 VTT
puh. vaihde (09) 4561, faksi 456 4374

VTT, Bergsmansvägen 5, PB 2000, 02044 VTT
tel. växel (09) 4561, fax 456 4374

VTT Technical Research Centre of Finland
Vuorimiehentie 5, P.O.Box 2000, FIN–02044 VTT, Finland
phone internat. + 358 9 4561, fax + 358 9 456 4374

VTT Tietotekniikka, Tietotie 3, PL 12021, 02044 VTT
puh. vaihde (09) 4561, faksi (09) 456 7012

VTT Informationsteknik, Datavägen 3, PB 12021, 02044 VTT
tel. växel (09) 4561, fax (09) 456 7012

VTT Information Technology, Tietotie 3, P.O.Box 12021, FIN–02044 VTT, Finland
phone internat. + 358 9 4561, fax + 358 9 456 7012

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Composite Video Traffic over IEEE 802.15.3a Wireless Personal Area Networks

Livio Viggiano[(1)], Ulrico Celentano[(1)], Ian Oppermann[(1)]

[(1)]Centre for Wireless Communications, University of Oulu
Tutkijantie 2E, PO box 4500,
90014 Oulu, Finland
Email: { livio.viggiano, ulrico.celentano, ian.oppermann} @ee.oulu.fi

Abstract
In this paper, transmission of multidimensional video traffic over IEEE 802.15.3a WPANs is presented. First, a statistical model for the multidimensional video source is presented and validated by comparison with real traces. Then, different resource allocation strategies implemented on top of IEEE 802.15.3 MAC are presented and their performance compared.

Keywords: MAC, Modelling, QoS, UWB, Video, WPAN.

1. INTRODUCTION

This work is part of the research performed at CWC within ULTRAWAVES EU-IST project. The scope of the project is to provide a wireless home connectivity solution for audio and video entertainment devices, based on IEEE 802.15.3 architecture and exploiting an UWB radio interface. The work presented here deals with L2 issues of the protocol stack within the domain of ULTRAWAVES.
In this paper, transmission of multidimensional video traffic over IEEE 802.15.3a WPANs is presented. First, the composite ULTRAWAVES video source is represented by a statistical model based on analysis of the source's properties. This model is validated by comparison of its statistics with those of real traces. Then, different resource allocation strategies are presented and their performance is compared using implementation of both strategies and IEEE 802.15.3 MAC [1] in OPNET network performance analyzer.

2. MULTIDIMENSIONAL VIDEO SOURCE TRAFFIC

The video traffic source considered in this work consists of three MPEG-2 [2] streams, each being a part of a unique panoramic, scene (Fig. 1). Three screens are positioned along a polygon arc with spectators located approximately in the polygon's centre.

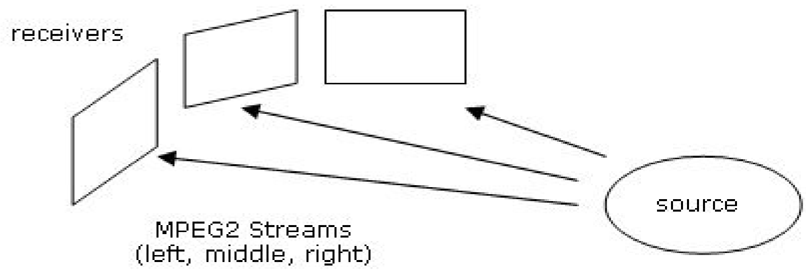

Fig. 1. The ULTRAWAVES scenario.

Since each triple of frames compose a snapshot of a single scene, those streams exhibit mutual correlation. Statistical properties of MPEG video traffic [3] show that using a Gamma probability distribution function (PDF) to model I, P, and B frame sizes gives good fitting with empirical data. The analyses performed in CWC on real multidimensional video streams confirm these results, and show how the three streams are correlated (Table 1).

Table 1. Correlation ρ between pairs of picture portions.

Video Stream 1	Video Stream 2	ρ
left	middle	0.9104
left	right	0.8699
middle	right	0.9187

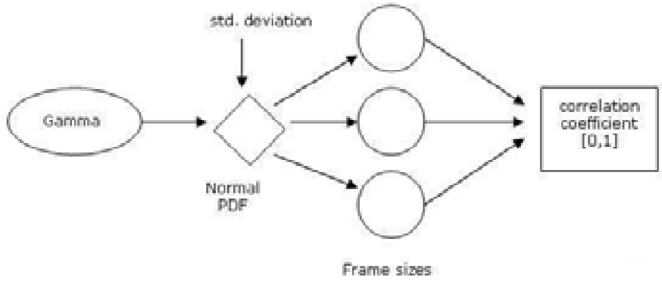

Fig. 2. The model for the multidimensional composite video source.

A proposed way to provide three different streams with identical distribution and with chosen correlation coefficient is presented in the following (Fig. 2). For each occurrence of an I, P, or B frame, a realization from a Gamma PDF with proper parameters is generated. Each realization is then used as arithmetic mean for a Normal PDF from which three different realizations are extracted. These values are the frame sizes of the three different streams generated by our model. Increasing and decreasing the standard deviation value of the Normal PDF between reasonable limits, allows us to obtain correlation coefficient be spread on all the interval [0,1]. Basically, the effect of this filtering is that the occurrences in the heaviest classes are shifted to the sides without being replaced by the same amount of occurrences coming from the closest classes. This means that the values are slightly more spread on the abscissa axis, with same mean but increased variance. Fig. 3 shows a graphic comparison of the original data with the one generated by filtering through a Normal PDF. It can be seen that the difference is reasonably small. Obviously, the larger the increase in the correlation between streams, the smaller are the changes in the shape of the streams.

This particular source has been implemented in OPNET network performance analyzer (version 6.0), allowing to simulate this multidimensional MPEG-2 video traffic according to the proposed procedure described above.

3. QOS SUPPORT IN IEEE 802.15.3 MAC

IEEE 802.15.3 MAC draft Standard presents a centralized, peer-to-peer communications system for short range applications [4]. In these wireless personal area networks (WPANs), interconnected devices (DEVs) are associated in a so-called piconet (PN). Among DEVs, the piconet coordinator (PNC) is selected. The PNC regulates in a centralized manner the traffic, which is however peer-to-peer. Both contention-based and contentionless accesses are available in the Standard. The IEEE 802.15.3 MAC superframe (SF) is shown in Fig. 4. With the beacon, the PNC informs each DEV on the composition of the fields following in the superframe, and on the allocation of the contentionless TDMA time slots. Channel time allocation (CTA) requests can be either asynchronous or isochronous. In the latter case, a dedicated pseudo static slot is granted to the device that has requested it to transmit high priority data. Resource allocation policies and quality of service (QoS) provision is on purpose left undefined in the Standard. This topic is addressed in this work.

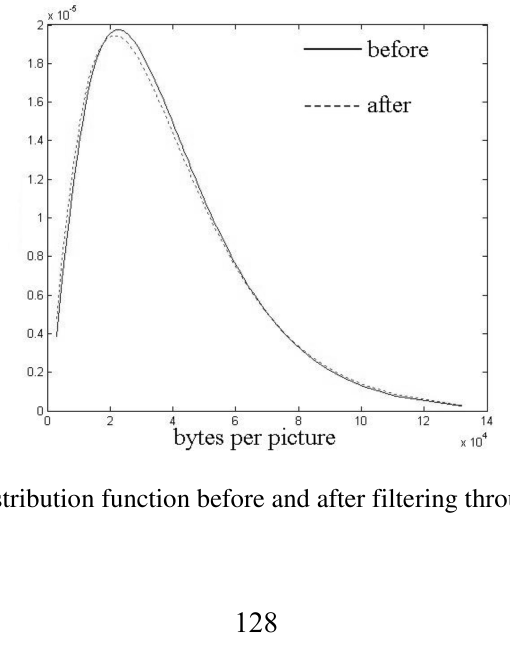

Fig. 3. Probability distribution function before and after filtering through the Gaussian PDF

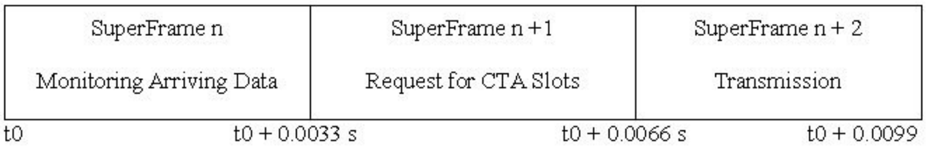

Fig. 4. The three-phase CTA negotiation procedure

In the scenario described in this paper, it is assumed that the same WPAN is used to carry delay-sensitive, high priority video traffic together with delay-insensitive, low priority background data. The latter traffic can be represented, e.g., by uploading or downloading data between a pair of DEVs of the WPAN. The scope of resource allocation schemes described here is to guarantee the requested quality to the video traffic whilst maximizing the throughput of background data traffic.
According to IEEE 802.1.D Informative Recommendation [5], when there are only two queues, QoS categories have to be intended for highest priority as Voice Traffic (i.e., requirement of less than 10ms delay), and for lowest priority as Best Effort. IEEE 802.15.3 suggests using isochronous channel time allocation (CTA) slots for high QoS categories (classes 3 to 6). In IEEE 802.15.3 MAC, despite the centralized policy, the acknowledgement of the required capacity is done by each device. A device that has to transmit a video stream is capable to choose how much capacity to ask to transmit its data. If the requested capacity is chosen equal to the peak of the video stream required bandwidth, then the delay will be close to zero, but there will be a huge waste of capacity. If the requested capacity is chosen equal to a value between the peak and the average of the traffic, then the efficiency of the allocation will increase, but this will introduce a delay that increases as much as the data comes with more jitter. An adaptive solution that increases the efficiency of time slots allocation until reaching the optimal performance, providing at the same time a QoS in terms of delay that respects Voice category specification is here presented. The superframe length is fixed in 0.0033 s. In each SF there is always at least one management CTA (MCTA) for each device. During each SF, the device is monitoring how many data need to be sent. In the following SF, an asynchronous channel time request command is sent by the devices within the assigned MCTA to inform the PNC of the needed amount of capacity. The PNC then counts the amount of high priority requests and if it is possible to satisfy all of them, allocates requested CTAs to each device for the upcoming SF. Since a cycle of monitoring-request-allocation is made by three SFs, if an high priority request can be satisfied, the delay introduced will be in the worst case (i.e., with data arrived at the beginning of the monitoring SF and scheduled at the end of the transmission SF) 0.0099. This value agrees with QoS specification above introduced. The efficiency of the resource allocation is optimal. Measuring the efficiency in terms of slots used to transmit packets over the number of allocated slots, η_m, it can be seen that with our proposed method this parameter reaches the maximum, which is the unit. An isochronous stream dimensioned on the peak will give η_p = (average value) / (peak value), while an isochronous stream dimensioned with a value between the average and the peak will give an η varying between η_p and η_m , but without any QoS guarantee. In implementing the resource allocation algorithm, reliability for the allocated streams is granted in the following way. Since IEEE 802.15.3 MAC suggests to use isochronous stream to grant a fixed amount of capacity, it ensures that an allocated stream will last as much as a device needs it. In order to provide this, the MAC is able to refuse isochronous streams when there is not enough capacity to satisfy the existing plus the new request, thus an ON-OFF policy. To emulate this behaviour using asynchronous requests, our MAC gives priority to the high priority streams already in service while deciding on a new allocation request. This means that in case of a very large request of resources, the last DEV trying to access the medium will be neglected service. (So, for example, in a home consumer electronic application scenario, a request to start a wireless videogame will not interrupt any portion of the movie watched possibly in the other room.) In addiction to that, there is a limit on the amount of capacity that each device can obtain. Since the radio interface that we are considering provides 110 Mbit/s, a fraction of the overall capacity is available to other devices in the piconet. Fairness is also provided in order to allow all the devices to transmit low-priority data with the same probability.

4. RESULTS

Evaluation of the performances of adaptive asynchronous allocation in terms of delay and efficiency are shown in the following.

In Fig. 5 are plotted the asymptotic values of the average end to end delay for several bit-rates. As shown, at 35Mbps the average delay is already pretty below the 0.1 s limit.
In Fig. 6 is shown how the dynamic allocation of the capacity minimizes the delay without wasting capacity. The comparison with a synchronous allocation at 110Mbps which gives delays pretty closes to the ones given by the dynamic allocation (Table 2) shows that using a dynamic allocation the average of occupied capacity decreases from the 58% to the 26%, freeing all the space wasted by the static allocation to other applications.

Table 2. Comparison between delays given by allocations of Fig. 6 at 110 Mbps

end to end delay (average)	DEV	SYNCH	DYN
	rcv 1	0.013	0.0074
	rcv 2	0.013	0.0120
	rcv 3	0.013	0.0160

5. CONCLUSIONS

In this paper, a statistical model for the multidimensional ULTRAWAVES video source has been presented. The model has been implemented in OPNET together with the model of IEEE 8021.5.3 MAC. On top of it, a resource allocation policy that provides reliable QoS for 802.1D data has been presented. The performance of this scheme has been studied and discussed. It has been shown that the proposed resource allocation scheme provides optimal performance in terms of allocation efficiency while having the delay kept within the category specification.

6. ACKNOWLEDGEMENTS

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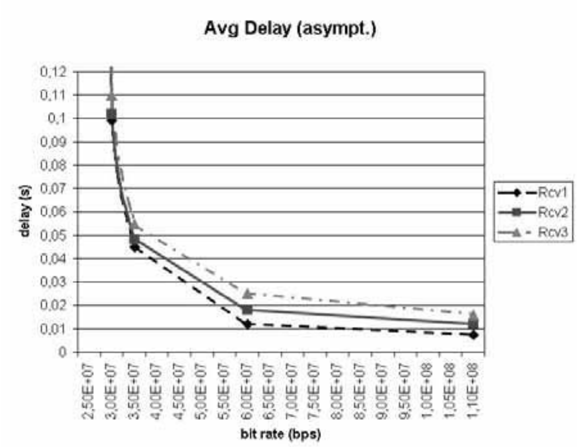

Fig. 5. End-to-end packet Delay for the three receivers with Dynamic Resource Allocation

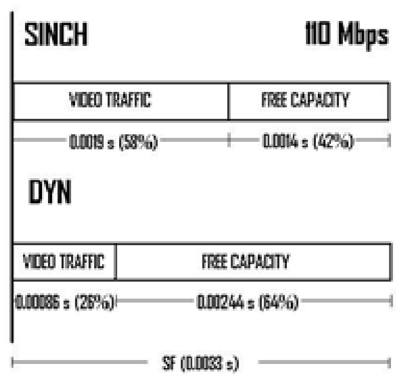

Fig. 6. Comparision between Synchronous and Dynamic Resource Allocation at 110 Mbps