Journal of Zhejiang University SCIENCE A
ISSN 1009-3095 (Print); ISSN 1862-1775 (Online)
www.zju.edu.cn/jzus; www.springerlink.com
E-mail: jzus@zju.edu.cn

Time allocation scheme in IEEE 802.15.3 TDMA mechanism*

LIU Xin, DAI Qiong-hai, WU Qiu-feng

(*Department of Automation, Tsinghua University, Beijing 100084, China*)

E-mail: liux01@mails.tsinghua.edu.cn; qhdai@tsinghua.edu.cn; wqf-dau@tsinghua.edu.cn

Received Dec. 8, 2005; revision accepted Feb. 18, 2006

Abstract: In network with a shared channel in TDMA mechanism, it is a core issue to effectively allocate channel time to provide service guarantees for flows with QoS requirements. This paper proposes a simple and efficient time allocation scheme called MES-ESRPT (MCTA at the End of Superframe-Enhanced Shortest Remaining Processing Time) for delay-sensitive VBR traffic in accordance with IEEE 802.15.3 standard. In this algorithm, PNC (piconet coordinator) allocates one MCTA (Management Channel Time Allocation) for each stream which is the process of communication at the end of superframe. During the MCTA period, each transmitter should report current fragments number of the first MSDU (MAC Service Data Unit) and the fragments number of the remainder MSDUs to PNC. In the next superframe, PNC firstly allocates part CTAs (Channel Time Allocation) for each stream based on the remainder fragments number of the first MSDU by SRPT rule, then allocates remainder CTAs for each stream based on all fragments number of remainder MSDUs by the same SRPT rule. Simulation results showed that our proposed MES-ESRPT method achieves significantly better performance in QoS for multimedia streams compared to the existing schemes.

Key words: Shortest remaining processing time (SRPT), MAC layer, TDMA, Quality of Service (QoS)
doi:10.1631/jzus.2006.AS0159 **Document code:** A **CLC number:** TN919.8

INTRODUCTION

Up to now, ultra-wideband (UWB) is the most preponderant candidate for IEEE 802.15.3a, which together with IEEE 802.15.3 MAC provides robust support for portable consumer digital imaging and multimedia applications. Research related to UWB has mainly been focused on the PHY layer or circuit implementation (Tsang and El-Gamal, 2005). The work in MAC layer presents a striking contrast to that in PHY layer. In UWB networks with a shared wireless channel, link arbitration is a core issue for flows with QoS requirements due to the stochastic character of the channel, the network being interference-dominated, and the bursty nature of multimedia traffic. Unfortunately, former research on wireless networks cannot be directly reapplied here because of their practical limitations. Some researches are based on wireless channel estimation, such as tracking the channel using feedback between the sender and receiver (Knopp and Humblet, 1995), using the channel side information (Goldsmith and Varaiya, 1986) or opportunistic scheduling with channel estimation (Viswanath *et al*., 2002). For multimedia traffic with arbitrary frame rates, the fidelity of the feedback diminishes when the frame interval is large (30 ms) compared to the channel variations. The gains of opportunistic scheduling are limited by the stringent latency requirements of MPEG-4 traffic resulting in a smaller time scale over which the users with a good or bad channel have to be scheduled in. Furthermore, channel averaging techniques using transmission rate and power adaptation to maximize network throughput require complex and high cost decoder designs (Goldsmith and Varaiya, 1986), do not work effectively under a delay bound (Viswanath *et al*., 2002), require frequent two-way packet exchange and need a large number of users to extract effective gains from

* Project supported by the National Natural Science Foundation of China (No. 60432030) and Distinguished Young Scholars of the Natural Science Foundation of China (No. 60525111)

multi-user diversity (Knopp and Humblet, 1995).

In this paper, we propose a simple and efficient MAC layer time allocation scheme called MES-ESRPT (MCTA at the End of Superframe-Enhanced Shortest Remaining Processing Time) to deliver timely guarantees for VBR (Variable Bit Rate) traffic with a centralized MAC mechanism. The centralized controller enjoys privileged access to the channel and is responsible for allocating medium access opportunities to every associated flow. The allocation algorithm in the centralized controller arbitrates which flow accesses the medium when, for how long and on which logical/physical channels.

The rest of this paper is organized as follows. Section 2 presents the network architecture and system description. Section 3 presents existing scheduling algorithms and analyzes their drawbacks, and then a detailed description of our MES-ESRPT scheme is given. Numerical results are compared in Section 4. Finally, conclusions are given in Section 5.

NETWORK ARCHITECTURE AND SYSTEM DESCRIPTION

Piconet architecture

The basic component in IEEE 802.15.3 is device (DEV). Two or more DEVs within a personal operating space (POS) communicating on the same physical channel comprise a piconet. One DEV is required to assume the role of PNC (piconet coordinator) of the piconet. The PNC always provides the basic timing for the WPAN. Additionally the PNC manages the QoS requirements, power save modes and access control to the piconet. The basic stucture of a piconet is shown in Fig.1.

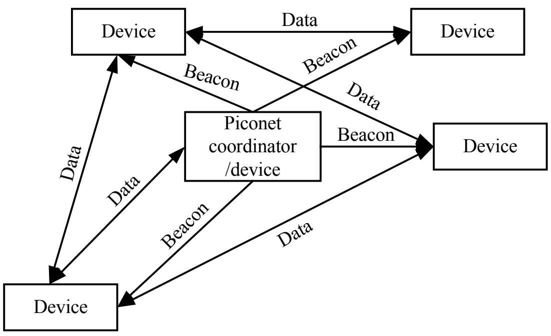


Fig.1 802.15.3 piconet elements

Channel time management

Data are communicated directly between source DEV and destination DEV after PNC broadcasts beacon with the time allocation of this superframe. Timing in the 802.15.3 piconet in UWB systems is based on the superframe illustrated in Fig.2 (Draft P802.15.3/D17, 2003).

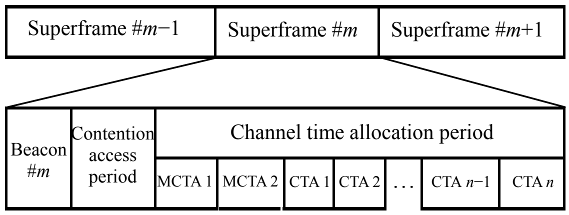


Fig.2 802.15.3 piconet superframe

The superframe is composed of three parts:

(1) The beacon, which is used to set the timing allocations and to communicate management information for the piconet.

(2) The contention access period (CAP), which is used to communicate commands and/or asynchronous data if it is present in the superframe.

(3) The channel time allocation period (CTAP), which is composed of channel time allocations (CTAs), including management CTAs (MCTAs). CTAs are used for commands, isochronous streams and asynchronous data connections. The length of the CAP is determined by the PNC and communicated to the DEVs in the piconet via the beacon. However, the PNC can replace the functionality provided in the CAP with management CTAs (MCTAs). MCTAs are a type of CTA that is used for communication between the DEVs and the PNC. The CAP uses CSMA/CA for the medium access. The CTAP, on the other hand, uses a standard TDMA protocol where the DEVs have specified time windows. MCTAs are either assigned to a specific source/destination pair and use TDMA for access or they are shared CTAs that are accessed using the slotted aloha protocol.

Channel simulation model

There has been much research to study the wireless channel model to determine the effect of fading on network performance. Wang and Chang (1994) investigated the accuracy of a first-order Markov process in modeling data transmission on a

Rayleigh fading channel. The simplest example of quantized model is two-level model. Zorzi *et al*.(1995) showed that a first-order binary Markov for the success/failure process is a good approximation. In this paper, we use two states Markov model to approximately represent the fading channel, as shown in Fig.3.

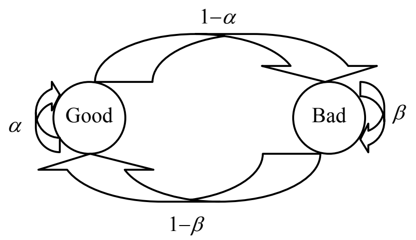


Fig.3 Two states Markov model for the fading channel

The transition probabilities matrix is given by

$$\boldsymbol{P}=\begin{pmatrix} P_{00} & P_{01} \\ P_{10} & P_{11} \end{pmatrix}=\begin{pmatrix} \alpha & 1-\alpha \\ 1-\beta & \beta \end{pmatrix}.$$

“0” stands for good state and “1” stands for bad state. We set different frame error rate (FER) in good/bad state. The term “frame” herein means MAC frame called MAC Service Data Unit (MSDU) in IEEE 802.15.3 standard. Frame error rate is the effective error rate seen by the MAC after error correction but does not include the effect of retransmissions.

System description

There are several MPEG-4 video streams within a piconet. In order to handle large data units from layers above the MAC sub layer, IEEE 802.15.3 standard supports the fragmentation and defragmentation of these data units. The fragments are numbered with a sequence number for the upper layer unit (MSDU) as well as a sequence number for the fragment (MPDU) itself. Video stream has deadline because of the decoding limitation. We suppose it is known by source DEV to save bandwidth. If the time between video frame arriving to source DEV in MAC layer and its transmission out from source DEV exceeds the deadline, source DEV will drop the video frame without informing destination DEV and automatically transmit next video frame. Source DEV detects the deadline limit before it transmits each MPDU. If one MPDU is overdue, all of the MPDUs having the same video frame number will be dropped without transmitting to upper layer even if some anterior MPDUs have been transmitted correctly to destination. For the purpose of saving power and simplicity, superframe is generally designed to be fixed. In this way, some DEVs without communication temporarily can sleep for some fixed time and wake opportunely at the beginning of each superframe. Each transmitter sends channel time allocation request to PNC during its own CTA and PNC will allocate channel time in later superframe based on all of the requests. Our object is to design a simple and efficient scheduling algorithm of channel time allocation for PNC in each superframe to reduce job failure rate (*JFR*) and increase throughput as much as possible. *JFR* is the rate at which video frames are dropped due to missing their deadlines.

ANALYSIS OF CURRENT APPROACHES AND PROPOSED MES-ESRPT ALGORITHM

To allocate each source DEV with fixed CTA in every superframe is the easiest conceivable method. However, the source DEV will still be allocated CTA even if it has no data to send. Thus the bandwidth is engaged unnecessarily. On the other hand, this method can transmit data in time sometimes because a source DEV will get CTA to send gustly arrival data although it does not request for CTA previously.

Mangharam *et al*.(2004) proposed an SRPT (Shortest Remaining Processing Time) method to momentarily update queue size of each stream by adding a byte to MAC header. With load information from every packet exchange, the PNC is aware of the instantaneous channel requirement of each flow, then the PNC can dynamically allocate the idle bandwidth of no load or lowly loaded nodes to the overloaded flows.

The SRPT method is advisable because the mean service response time is minimized by servicing the shortest jobs first. However, there is slight imperfection that this scheduling algorithm needs to add one additional byte to MAC header. This byte is used to inform PNC the current queue size. This part is inadvisable for the following reasons: firstly, it does some alteration to standard; secondly, the destination must be PNC since source DEV informs queue size in the process of transmission data; thirdly, this scheme requires too much processing overheads for the additional queue information field in the MAC header which will waste bandwidth to a large degree; fourthly, it is only effective when superframe is dynamic. Whereas the case of dynamic superframe is disadvantageous for power management as mentioned before.

We know that MCTA is a type of CTA which is used for communication between the DEVs and the PNC. Therefore MCTAs can be considered to transmit current queue size of each flow. The advantages of utilizing MCTAs are: (1) The improvement is in accordance with IEEE 802.15.3 standard; (2) The destination DEV can be optionally chosen unnecessarily confined to PNC since queue size information and multimedia data are transmitted in different CTAs; (3) The overheads of queue size information transmission are greatly reduced because it is only once in a superframe for each flow in our scheme while it is equal to the number of MPDUs transmitted in a superframe for each flow in former scheme.

The following problem to solve is to confirm the situation of MCTAs in a superframe. We may doubt the accuracy and timeliness of load information in our scheme compared with momentarily update scheme. In fact, the momentarily update method cannot achieve the effect of momentarily update. If the CTA lies in the anterior of superframe, the queue size may increase a lot at the end of superframe, thus PNC can not acquire the factual momentary queue size. It is unnecessary to inform the queue size to PNC when source DEV transmits each MPDU because PNC makes the channel allocation decision only after the superframe is over. Therefore, we allocate one MCTA for each flow and put them at the end of superframe in sequence. During MCTA the source DEV is in charge of reporting its current queue size request to PNC.

After PNC collects the load information from last superframe, it will make time allocation decision in terms of a scheduling scheme. In SRPT scheduling scheme PNC allocates channel time in the ascending order of the queue size of each flow until there is no idle time remained in current superframe. By minimizing the number of outstanding requests in a system, Little's Law supports the fact that SRPT minimizes the aggregate mean response time of the system. The object in this paper is to design a proper scheduling algorithm to reduce *JFR* as much as possible, namely to increase Job Success Rate as much as possible. In a limitary duration we can increase Job Success Rate through enhancing service rate, or reducing mean service time for the jobs having the same deadlines. In SRPT scheme it's inapposite to consider the queue size as the whole because the queue consists of a few video frames with different deadlines. The optimized scheduling algorithm should be to sort all of the jobs, then to process the jobs in urgent order and process the jobs having the same deadlines based on SRPT. It's too complex and infeasible to sort all of the video frames in urgent order. To tradeoff between the complexity and the performance, we group the video frames having similar deadlines. We divide all of the video frames into two groups: the first video frame and the remainder video frames. For these two groups of video frames we adopt SRPT scheduling algorithm respectively and the final CTA allocated to each stream is the sum of the two parts.

In a word, compared with momentarily update-SRPT method, the MES-ESRPT algorithm does not need to limit the receiver to be PNC and accords with IEEE 802.15.3 standard. Meanwhile the overheads of load information are greatly reduced. Last but not least, MES-ESRPT method always obtains the least *JFR* and the greatest throughput in different parameters cases.

NUMERICAL RESULTS

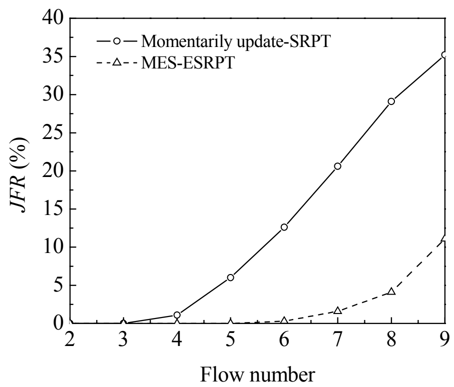
The simulation environment is under Network Simulator 2 (ns-2). We use an MPEG-4 traffic generator that generates traffic which has the same first and second order statistics as an original MPEG-4 trace. The related codes were embedded in ns-2. The MAC layer payload data rate is set to 110 Mbps, 200 Mbps, and 480 Mbps respectively and the physical preamble is assumed to be 15 μs. MAC overheads such as header size, guard times, aFirstCTAGap, SIFS and MIFS are set as regulated in 802.15.3 Draft D17. We utilize first-order two states Markov frame error model to approximately represent the wireless channel. In this simulation we set *FER*=0.0 in good state and *FER*=0.15 in bad state. The average duration time of good or bad state should be hundreds of milliseconds since the typical channel model is a slowly decaying channel in UWB systems. We change channel state between superframes. Since dynamic superframe is disadvantageous for power management as mentioned before, simulation is run for static superframe only. Superframe size (SFS) is set to 15 ms, and the average duration of channel state is set to 50 slots that are equal to 750 ms. To study the case of multi flows combining together, we set the interval of different flows to 100 ms. We only consider interactive video traffic such as wireless network conferences and interactive games whose deadline should be less than 100 ms. We set deadline of all flows to 60 ms. In order to get results with statistical meaning, we set simulation duration to 800 s including about more than one thousand of average durations of channel state. Maximum fragment size (payload in MAC layer) is set to 1 kbytes. In all the numerical examples, previous parameters are constant. Bandwidth is 110 Mbps and 200 Mbps respectively. Code rate of each flow is 6 or 8 Mbps.

From the knowledge of coding and decoding, we know that if I frame is lost or wrong, other frames of this GOP will not reconstruct even if other frames are transmitted correctly. So we use such a formula to compute *JFR*:

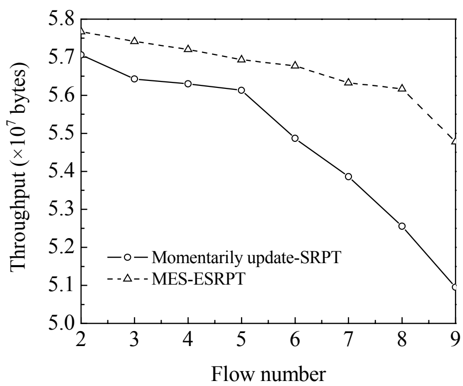
$$JFR = \frac{(L_I \times 12 + L_P + L_B)}{N} \times 100\%,$$

where L_I, L_P, L_B are the lost numbers of I-, P-, B-frames respectively, and N is the total number of frames that source DEV should transmit to destination. Another performance index is throughput equal to the total correctly received payload bytes in the destination DEV.

We first look at the case where FER_G=0, FER_B=0.15, fixed SFS=15 ms, simulation duration= 800 s, flow interval=100 ms, payload=1 k, deadline=60 ms, bandwidth=110 Mbps, code rate=6 Mbps. Number of flows varies from 2 to 9. *JFR* and throughput are plotted versus flow counts in Fig.4. Momentarily update-SRPT time allocation scheme is also shown for comparison. We can see that MES-ESRPT method always gets the least *JFR* and the greatest throughput. In general *JFR* is a key factor that affects network capacity to a large extent. If we assume the *JFR* under 5% is acceptable, the capacity is eight number flows for MES-ESRPT method while it is only four number flows for momentarily update-SRPT method. When the flow number is eight in a piconet, *JFR* of our MES-ESRPT method is only 4.1% while that of momentarily update-SRPT method is 29.1%. Our MES-ESRPT method slackens the trend of *JFR* increasing rapidly with the flow number. Similarly Fig.4b shows the distinct difference in throughput between momentarily update-SRPT and MES-ESRPT.



(a)



(b)

Fig.4 Bandwidth=110 Mbps, code rate=6 Mbps. (a) *JFR* vs flow count and (b) throughput vs flow count

In Fig.5, the situation is the same as in Fig.4, except that bandwidth is 200 Mbps and code rate is 8 Mbps for each flow. Since bandwidth is relative enough if flow number is less than five, the differences of momentarily update-SRPT and MES-ESRPT in throughputs are unapparent. *JFR* is discriminative even if the flow number is small because SRPT priors video frame with small queue size ignoring more I frames than ESRPT.

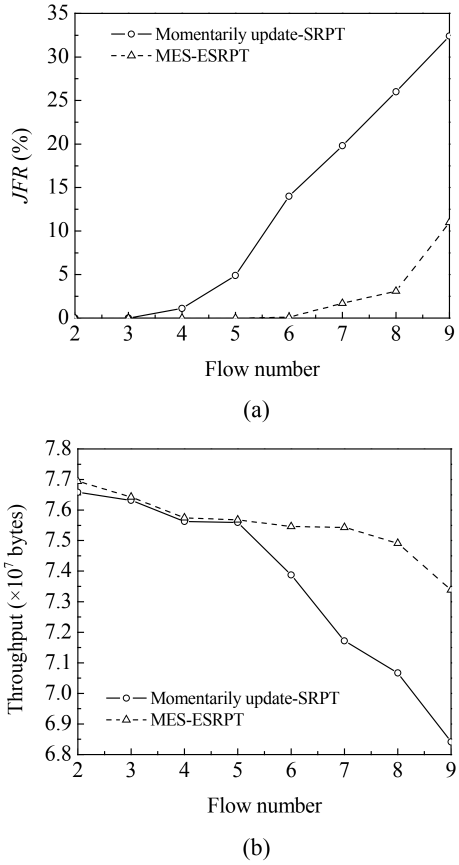


Fig.5 Bandwidth=200 Mbps, code rate=8 Mbps. (a) *JFR* vs flow count and (b) throughput vs flow count

CONCLUSION

In this work, a time allocation scheme called MES-ESPRT (MCTA at the End of Superframe-Enhanced Shortest Remaining Processing Time) based on IEEE 802.15.3 standard was studied in a time-varying wireless slow fading channel environment. A simple two states Markov model was used: good channel state and bad channel state, in which Frame Error Rate (FER) was different. In this algorithm PNC allocates one Management Channel Time Allocation (MCTA) for each stream which is in the process of communication at the end of superframe. During the MCTA period, each transmitter should report current fragments number of the first MSDU (MAC Service Data Unit) and the fragments number of the remainder MSDUs to PNC. PNC will allocate corresponding channel time in the next superframe based on these by SRPT rule. In comparison with other existing methods, our MES-ESPPT method always gets the least job failure rate (*JFR*) and the greatest throughput in different parameters cases in simulating ns-2 environment. Our algorithm is very effective and simple, so it is viable for power save mode applications such as WPAN.

References

Draft P802.15.3/D17, 2003. Draft Standard for Telecommunications and Information Exchange between Systems —LAN/MAN Specific Requirements, Part 15.3: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for High Rate Wireless Personal Area Networks (WPAN).

Goldsmith, A., Varaiya, P., 1986. Capacity of fading channels with channel side information. *IEEE Transactions on Information Theory*, **43**(6):1924-1934.

Knopp, R., Humblet, P., 1995. Information Capacity and Power Control in Single-Cell Multi-User Communications. Proc. IEEE International Conference on Communications (ICC'95). Seattle, USA.

Mangharam, R., Demirhan, M., Rajkumar, R., Raychaudhuri, D., 2004. Size Matters: Size-based Scheduling for MPEG-4 over Wireless Channels. SPIE Conference on Multimedia Computing and Networking.

Tsang, T.K.K., El-Gamal, M.N., 2005. Ultra-Wideband (UWB) Communications Systems: An Overview. The 3rd International IEEE-NEWCAS Conference, p.124-129.

Viswanath, P., Tse, D., Laroia, R., 2002. Opportunistic beam-forming using dumb antennas. *IEEE Transactions on Information Theory*, **48**(6):1277-1294. [doi:10.1109/TIT.2002.1003822]

Wang, H.S., Chang, P., 1994. On Verifying the First-order Markovian Assumption for a Rayleigh Fading Channel Model. Third Annual International Conference, p.160-164.

Zorzi, M., Rao, R.R., Milstein, L.B., 1995. On the Accuracy of a First-order Markov Model for Data Transmission on Fading Channels. Fourth IEEE International Conference, p.211-215.