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Performance Evaluation of WiMedia UWB MAC Protocol Algorithm Supporting Mixed Video and Shipboard Control Data Traffic

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Abstract

This paper applies WiMedia UWB network into a wireless ship area network (WSAN) so as to support high-quality multimedia services on board and reliable instrument control information as well, since the need for mixed high-quality video traffic and shipboard control data traffic is essential for a high-cost valued digital ship. Thus, in this paper, prioritized contention access (PCA) and distributed reservation protocol (DRP) based on WiMedia UWB (ECMA-368) MAC protocols are combined and proposed to such mixed traffic environment, by varying the portions of superframe according to traffic type. It is shown that the proposed WiMedia UWB MAC protocol can provide reliable mixed video and shipboard control data traffic as well.

Keywords: *WiMedia, UWB, wireless ship area network, ECMA-368, video traffic.*

1. Introduction

The typical ship area network (SAN) architecture is generally organized as a single network with a backbone network that is standardized by the international electro-technical commission (IEC). Within a ship area network, shipboard instruments are connected based on the conventional controller area network (CAN), i.e., IEC61162-3 standard and national marine electronics association (NMEA) 2000 standard, supporting up to 50 nodes to share a common bus at 250 kbps. These ship area and controller area networks are mainly based on wired networks such as dedicated connections, instrument networks, and shipboard control networks with Ethernet connection. The main operations of such networks are sensing and control shipboard systems and management of crucial information for safety and navigation, which are performed in many parts of the vessel from the engine room, to the bridge, to the administrative personnel, and even off of the ship to the owner’s office.

However, the data rate of the typical CAN connection is limited to 125kbps, and thus such networks

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cannot provide the increasing need for large amount of data transmission on board between a bunch of instruments and an integrated gateway. Moreover, it is essential to apply state of the art wireless communication technology to such ship area network for providing multimedia data service and high-quality video streaming service within a high-valued added vessel, i.e., digital ship. For this purpose, a wireless gateway is necessary so as to support high-quality video traffic and information data combined with shipboard control information for the sake of energy efficiency, system deployment cost, and recovery and management convenience.

As a wireless transmission technology for a wireless gateway, WiMedia ultra wideband (UWB) MAC is reasonable option, since it has been verified to satisfy the demand of multimedia video traffic services with high quality in a wireless home network environment, as well as a variety of applications such as wireless USB and wireless IP [1]. The WiMedia UWB systems can support various data rates ranging from 53.3 to 480 Mbps over distances up to 10 meters, which was standardized by the European Computer Manufacturers Association (ECMA) International as the ECMA-368 standard [2]. For high data rates wireless personal area networks (WPANs), the ECMA-368 standard defined physical and MAC layers, which offer a number of policies and control mechanisms to ensure the QoS provisioning. The main feasible advantages of WiMedia UWB more suitable for the WPAN are high data rate, low power and precise positioning. The ECMA-368 standard defines the physical and media access control (MAC) layers for high rate WPANs.

WiMedia UWB provides two categories of MAC protocols such as a contention based prioritized channel access (PCA) for synchronous data communication service and a reservation based distributed reservation protocol (DRP) for isochronous service. Note that both of them have their pros and cons. Reservation based protocol can ensure the QoS with a lower resource utilization at peer-to-peer transmission in mesh or ad-hoc networks. On the other hand, contention based protocol are flexible and efficient in sharing resources by bursty traffic and they can achieve a certain level of multiplexing gain. However, their performance may degrade severely when the network is congested and collisions occur frequently. Like IEEE 802.15.3, WiMedia UWB (ECMA-368) MAC is based on time slotted superframes. In each superframe, a portion of the channel time is reserved and the remaining can be used for contention-based transmissions [2].

This paper focuses on feasibility of both DRP and PCA MAC protocols into a wireless gateway with WiMedia UWB transmission technology, which should deliver high quality video stream service as well as a bunch of shipboard control information data for a high value added vessel. For this, this paper evaluates the feasibility of contention and reservation combined MAC protocol controlled by characteristics of incoming mixed data traffic. This dynamic MAC protocol approach is based on varying the portions of two data periods, i.e., DCA data period and PCA data period. In this paper, WiMedia UWB wireless gateway for providing physical and MAC layer connectivity between different instruments is connected to the same WAPN piconet area.

As such a wireless gateway, WiMedia UWB device is a very good option so as to provide reliable high quality data transmission and flexible network deployment. Thus, a WiMedia UWB wireless gateway is taken into account applying dynamic DRP and PCA MAC protocol in accordance with traffic characteristics. The rest of this paper is organized as follows: In Section 2 we present the WiMedia UWB based wireless gateway concept suitable for ship area network architecture. In Section 3 we present an overview of the WiMedia UWB MAC protocols and the proposed dynamic DRP and PCA scheme. Section 4 shows the simulation results and discussion of the proposed approach, followed by the conclusion.

2. WiMedia UWB based Wireless Gateway for Ship Area Network

2.1. Conventional Ship Area Network

A conventional ship area network has the functionality of a remote control and autonomous management of various sensors and instruments embedded or boarded on a ship. An integrated navigation system on board ship using NMEA2000 standard is primarily designed to provide two-way communication between the ship's navigational equipment such as radar, GPS receiver, automatic identification system (AIS), Gyro compass etc. NMEA 2000 is based on CAN, which is standardized by ISO. NMEA 2000 standard also became the international standard under IEC. Various instruments with the NMEA standard are connected to one central wired backbone cable. The backbone powers each instrument and relays data among all of the instruments on the network [3]. The first version of shipboard data architecture developed by the IEC standard is the Maritime Information technology Standard (MiTS) project. This uses four layers: instrument, process, system, and administrative. MiTS was developed as an integrated ship control (ISC) protocol, which could integrate an NMEA network on the bridge with industrial data network in the automation system [4], [5]. The conventional ship area network architecture is shown in Figure 1.

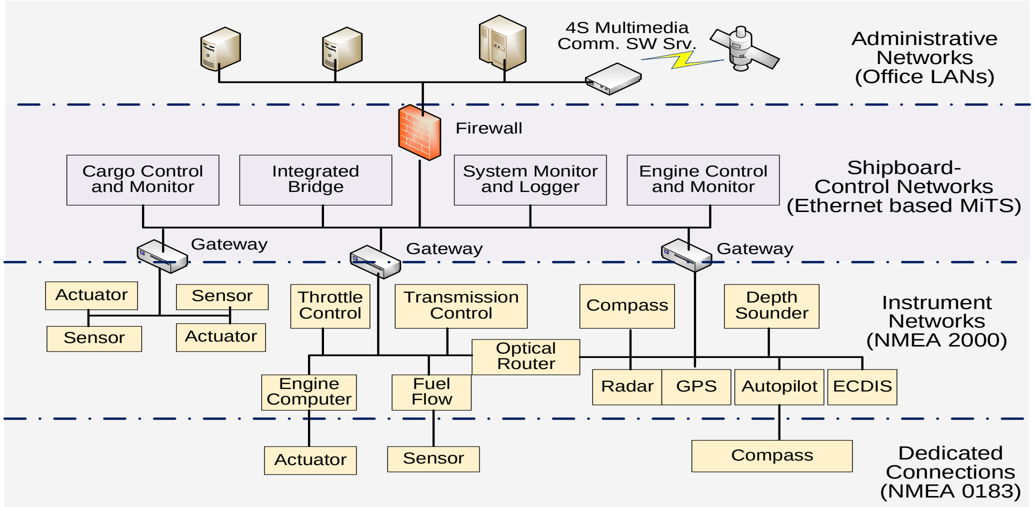

Figure 1. Conventional layered ship area network architecture based on international standards [4].

2.2 WiMedia UWB based Wireless Gateway

Instruments and devices in either a shipboard control networks or instrument networks are subject to a gateway, which is directly connected to the integrated bridge by Ethernet based wired network. However, aforementioned conventional ship area network cannot support sufficient data throughput performance to satisfy rapidly increasing amount of data caused by a bunch of various instruments, devices, and high quality video streaming service. It is noted that wireless communication technology has many advantages such as system deployment cost and recovery and management convenience, compensating an inherent drawback of the wired network.

For these reasons, this paper applies WiMedia UWB wireless gateway structure between shipboard control network and instrument network, which had been presented in our previous work in [6], [7]. Based on this conceptual structure proposed in [6], a modified WiMedia UWB based wireless gateway model supporting mixed video stream traffic and shipboard control data can be depicted as shown in Figure 2, wherein

WiMedia UWB WPAN piconet composes wireless coverage within the integrated network architecture of the SAN.

In the proposed architecture, a WiMedia UWB piconet network coordinator (PNC) plays as a WiMedia UWB wireless gateway and each WiMedia UWB device is a wireless transceiver connected to either/both navigational instrument or/and video service terminal. Note that the wireless WiMedia UWB communication technology gives a degree of freedom in deploying infra-nodes and reliable networking with each device. For support of high quality video stream service, WiMedia UWB device connected to user video terminals or instruments should be capable of supporting high-speed data transmission with low latency, high quality and transmission reliability. Moreover, it is noted that MAC protocol of WiMedia UWB should take into account the resource utilization efficiency, QoS, and QoE for such a mixed traffic with different priority.

Thus, the proposed WiMedia UWB MAC protocol as a wireless gateway focuses on designing of how to allocate the portions of data period into the contention based prioritized channel access and the reservation based distributed reservation protocol, i.e., a dynamic PCA and DRP protocol, which is to overcome the network congestion caused by contention only protocol, and to resolve the resource under-utilization caused by strict reservation protocol. In particular, it should be noted that this paper considers the uneven priority case of mixed video stream data and shipboard control data traffic, where shipboard control data is very important information to be transmitted with no latency but with low data rate requirement. Thus, a reasonable and resource efficient mechanism is necessary to deal with such high priority data traffic. Although this kind of data requires small amount of channel time slot data period, the since this cannot mixed with other video stream data traffic into the same WiMedia UWB media access slot (MAS).

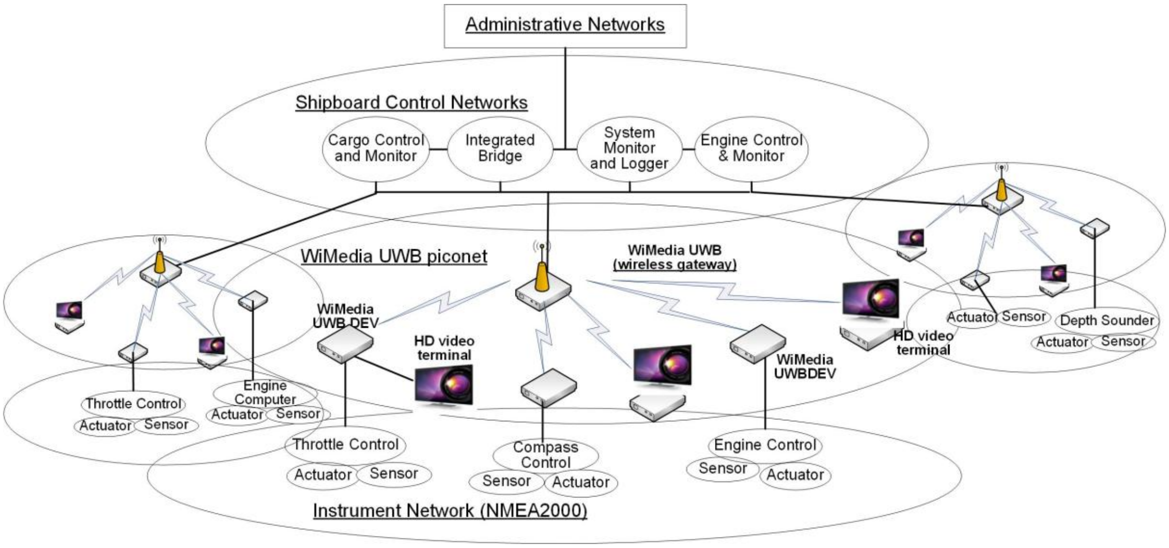

Figure 2. Proposed WPAN piconet model of the SAN with WiMedia UWB wireless gateway supporting mixed video stream data and shipboard control data.

3. Proposed Hybrid WiMedia UWB MAC Protocols (ECMA-368) for Mixed Data Traffic

3.1 WiMedia UWB MAC Protocols

We adopt the WiMedia UWB MAC specified in the ECMA-368 standard in our consideration. In such WiMedia UWB MAC, the channel time is divided into a time unit of a superframe, which has has a fixed length of time windows, called a medium access slot (MAS). The superframe consists of 256 MASs. The length of the superframe is 65.536ms, and the length of each MAS is 256 μs. In Figure 3, each superframe starts with a beacon period (BP), which extends over one or more contiguous MASs. A BP consists of beacon slots, and each device sends its own beacon in a non-overlapping beacon slot with others. Thus, devices need to search free beacon slots that are unused in the beacon period so as to send their beacons. The remainder of MASs in the superframe are used to transfer data, and it is called a data period. The length of a BP may be less than that of a data period. These IEs has timing and control information of users to access the channel in a fully distributed manner and synchronize. The beacon frames represent information about current users and a view of the network which helps the incoming user to identify empty beacon slots, occupy it and transmit its beacons.

The beacon frames are also used to reserve MASs in the DTP. A data period is divided into two types of MAS blocks. A contention-based protocol works during the one MAS block, and a reservation-based protocol works during another MAS block. The contention-based protocol is known as PCA, and it is similar to IEEE 802.11e for multiple prioritized classes. The PCA provides differentiated and distributed contention access to the medium for four access categories (ACs) in a device for asynchronous traffic transmissions. The PCA offers differentiated priorities to the four ACs for CSMA/CA-based medium access, respectively [2].

The reservation-based protocol is known as DRP. DRP enables devices to reserve one or more MASs that the device can use to communicate with one or more neighbors. All devices which use the DRP for data transmission or reception should announce their reservations by including DPR IEs(Information Elements) in their beacons. Reserved MASs mean the set of MASs in which the DRP provides reservation owner devices with exclusive access to the medium. Since DRP is a contention free channel access scheme, it has the important role to guarantee the QoS to isochronous traffic such as real-time streaming. It is used by devices to negotiate and reserve bandwidth. Also, the DRP enables devices to reserve one or more MASs that the device can use to communicate with one or more neighbors. DRP is used to reserve the MASs mostly for isochronous traffic or nodes that need guaranteed access to the medium, while PCA provides differentiated channel access to the medium similar to IEEE 802.11e [8].

A reservation of MASs guarantees a period of time for transmission during which the reservation owner has exclusive access to the medium as shown in Figure 4 [2]. A device that wishes to establish a reservation negotiates the channel time with its communication peer. There is no need for a central entity that controls the reservation process. In DRP, a device can only establish a reservation during the MASs that are not being used by another existing reservations. All devices that use the DRP for transmission or reception shall announce their reservations by including DRP IEs in their beacons. When a node wants to reserve MASs, for data transmission or reception, it negotiates with its neighbors via DRP IE reserves a set of MASs. The DRP frame contains a number of IEs representing different pieces of information. The DRP contains the control IEs, which shows owner, status of reservation, reason codes, reservation types and some more information about the reservation conflicts. The device that wants to start the reservation process is called the owner and the device that receives the information for reservation is referred to as target. The type of reservation can be hard, soft, PCA, private or alien BP. The Reservation status indicates the status of the DRP negotiation process which shows that whether a reservation is under negotiation, in conflict or established. The Reason Code is used by a reservation target which shows that whether a DRP reservation request was successful or not.

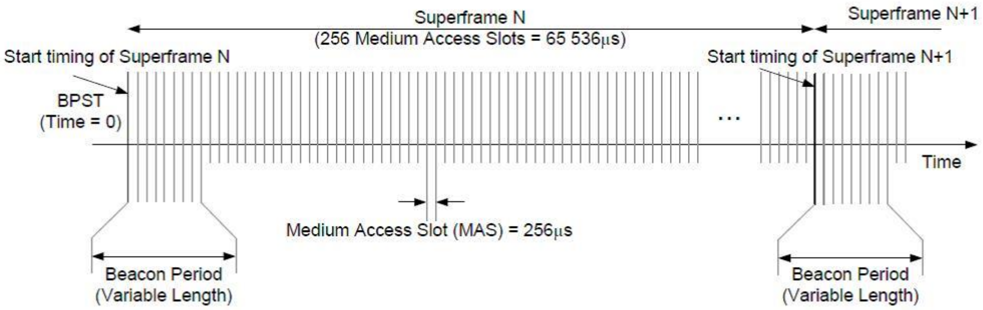

Figure 3. Structure of superframe WiMedia UWB (ECMA-368) MAC [2].

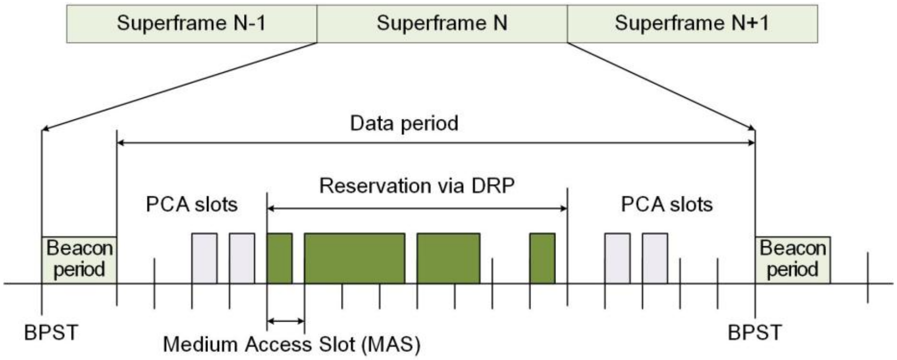

Figure 4. Structure of DRP and PCA.

In WiMedia UWB MAC, PCA is based on carrier-sense multiple access with collision avoidance (CSMA/CA) and employs different contention parameters in order to support both non-real-time and real-time data transfers, and to contribute to network scalability. In PCA, four access categories (ACs) of traffic are defined, which are called voice, video, best effort, and back-ground. The PCA procedures are applied by any devices for each AC to obtain a transmission opportunity (TXOP) for the frames belonging to that AC using the PCA parameters associated with that AC. Each time a device has a frame to transmit it will first sense the channel and occupy a free channel to start communication with the target device. Note that PCA is an extension to IEEE 802.11e's enhanced DCA protocol. PCA medium access is contention-based and prioritized by the Contention Window (CW) size and the Arbitration Inter-Frame Space (AIFS). Based on a backoff procedure specified in [2], the backoff counter is uniformly chosen from $[0, CW_k]$, where $k = 1, 2, \cdots, K$ is the index of the backoff stage, and K is the retry limit. The station shall sense the medium to become idle for AIFS and then decrease the backoff counter for each following backoff slot. If the channel is idle, the backoff slot has a fixed duration. Otherwise, if the channel is busy, the station should also wait for a Short Inter-Frame Space (SIFS) plus the Immediate-Acknowledgment (Imm-ACK) frame transmission time after the end of the data frame. Therefore, for higher priority ACs, the value of CW must be lower so that the higher priority node spends less time in the backoff state [2].

When the backoff counter is decreased to 0, the station obtains a Transmission Opportunity (TXOP) and can send out the frame at the beginning of the next backoff slot. A packet will be discarded when all the transmission attempts up to K have failed. The priorities are represented by the length of arbitrary inter-frame space (AIFS). Voice is given high priority with a shorter AIFS, followed by video and then by best effort traffic. A device shall wait for the medium to become idle for AIFS seconds before obtaining a TXOP or starting/resuming decrementing the backoff counter for the AC. Each device sets the value of CW to a value in range of minCW and maxCW after invoking a backoff for the AC.

WiMedia UWB ECMA-368 standard specifies physical layer, which transmits over the unlicensed 3,100~10,600 MHz frequency band. The supported data rates are 53.3, 80, 106.7, 160, 200, 320, 400, and 480 Mbps. The support for transmitting and receiving data rates of 53.3, 106.7, and 200 Mbps is mandatory. The data rates are dependent on modulation and coding rates [2].

3.2 Proposed WiMedia UWB MAC Protocols Supporting Mixed Data Traffic

As aforementioned, DRP is suitable for real-time traffic with a constant bit rate, while PCA can support bursty traffic more efficiently. In this paper, we have to consider a dynamic reservation and allocation scheme so as to take the advantages of both protocols for support of video streams as well as shipboard control data, by combining the reservation and contention-based MAC protocols.

For shipboard control data traffic, most data traffic within the vessel carry control and status information and thus, traffic must be lossless with low latency allowance. The traffic types of shipboard control data within a SAN considered in this paper are data from GPS, integrated navigation system (INS), voyage data recorder (VDR), AIS, gauge NN1 (the device for measuring balance of the ship), and Web server PC.

While DPR plays an important role to guarantee the QoS of isochronous traffic, the MASs are allocated by DRP without prior knowledge of the traffic load or priority. It should be noted that the ECMA-368 standard defines a number of DRP reservation methods such as hard, soft, private, and PCA. Thus, the MAS allocation need to be carefully handled during the beacon period and proper MAS access mechanism should be used as in [9]. From these reasons, the dynamic reservation based on the traffic load and its priority is considered in this paper. By the conventional strict DRP allocation method, it could degrade the performance of the network. Hence, in this paper, we divide the superframe into two main parts such as DRP and PCA and then, divide the DRP period into hard DRP region and soft DRP region as shown in Figure 5.

By the conventional approach, for isochronous traffic such as voice and video traffic, MAC reserve the MASs based on hard DRP and for asynchronous data traffic, the PCA part are reserved. However, in this paper, we need to consider the shipboard control data traffic with low latency and high priority but with small amount of data. It should be noted that such shipboard control data traffic could degrade the achievable data throughput performance of the WiMedia UWB network, since this requires hard DRP MASs for high priority. If the overall traffic is not congested because of less video stream service request, the DRP region is sufficient enough to serve the mixed video and shipboard control data traffic. On the other hand, if the traffic is congested by increase of video stream service, each devices need to wait and carefully reserve the MASs. Therefore, we propose the dynamic DRP and PCA allocation method based on traffic congestion as shown in Figure 6.

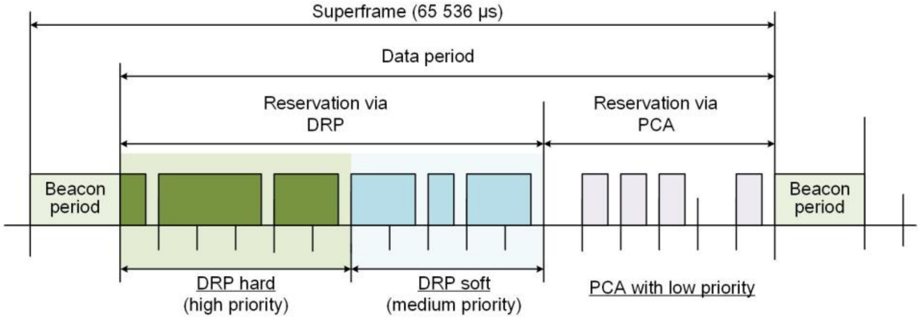

Figure 5. Structure of dynamic DRP and PCA reservation approach.

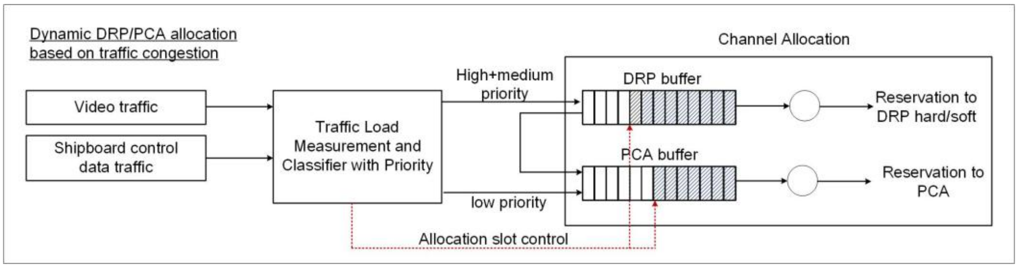

Figure 6. Proposed dynamic DRP and PCA reservation scheme based on traffic load.

As shown in Figure 5 and Figure 6, we adopt the logical block of the traffic load measurement and classifier. With this block, it is assumed that the WiMedia devices can classify and the arriving mixed video stream traffic and the packetized shipboard control data traffic. Since we use a dynamic DRP and PCA reservation based on the traffic load condition and priority, we do not fix either DRP region or PCA region as shown in Figure 5. Basically, the WiMedia UWB devices occupy the MASs on first come first serve basis. However, the WiMedia UWB device containing shipboard control data traffic can reserve MASs by hard DRP prior to other traffic. Based on arrival traffic and traffic congestion condition, the logical bounds of MASs can be varied according to traffic condition on a superframe basis or a couple of superframes basis.

For isochronous video traffic, the devices can reserve the hard DRP or the soft DRP if available. If the DRP buffer is full, these devices with video traffic can reserve the PCA MASs if available. All connected devices can use the DRP service primitive parameters such as the desired bandwidth, available bandwidth and minimum bandwidth. Using these parameters, each device can estimate that how much bandwidth is available in the system.

4. Simulation and Discussion

As a simulation platform, we use Matlab simulation tools for the performance evaluation of the WiMedia UWB based on ECMA-368 MAC piconet applying wireless gateway concept. We focused on the feasibility performance of WiMedia UWB MAC in the mixed traffic. In implementing the simulator, we simulate mixed traffics such as video stream traffic and shipboard control data traffic. It is assumed that randomly 5, 10, 15 distributed devices (nodes) are connected to either shipboard instruments or HD video terminal in a vessel. In simulation model, we consider three connected network cases with respectively 5, 10, and 15 nodes and each devices have a data rate of 480 Mbps. The duration of a time slot is 256 µs. The frame size of video traffic considered is 20,209 bytes and the shipboard control traffic is up to 2,048 bytes. The other simulation parameters are based on simulation set up in [10], [11].

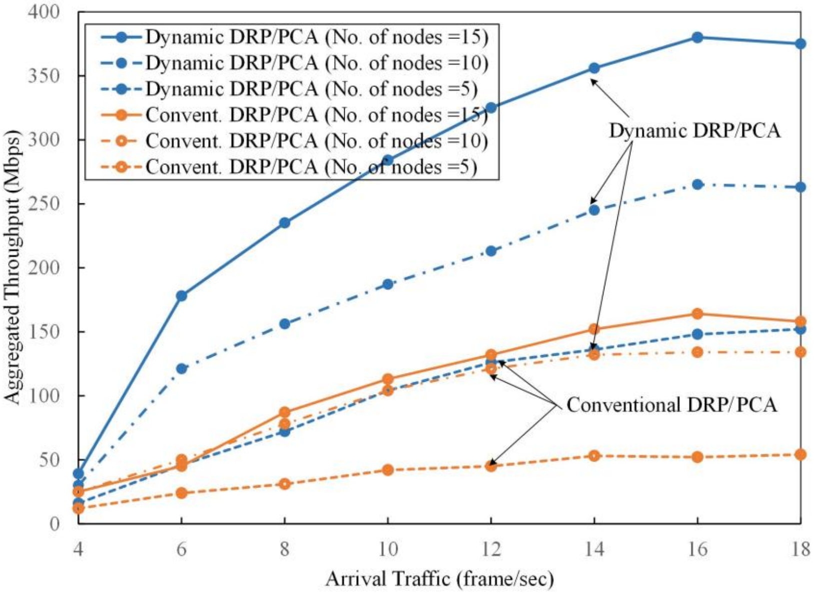

Figure 7. Aggregated throughput of the dynamic DRP and PCA allocation without shipboard control data traffic (video only traffic).

Figure 7 shows the aggregated throughput of the dynamic DRP and PCA allocation protocol as a function of arrival video traffic compared with the conventional DRP and PCA allocation with strict reservation rule. As shown in Figure 7, a high throughput performance is achieved when the reservation method is dynamic and flexible and the number of devices served is increased. For video only traffic, the achievable throughput is very dependent on the number of devices to carry out data. However, it is noted that the reservation method employed in MAC plays an important role in improving the throughput performance.

As shown in Figure 7, the conventional DRP and PCA approach with a strict reservation rule cannot achieve a high throughput performance when the arrival traffic increases and causes traffic congestion of the network irrespective of sufficient channel available. Once the portions of superframe are fixed for DRP and PCA traffic types, the flexibility of reservation cannot be expected. This increases the probability of packet drop due to the lack of available channel as the arrival traffic increases. Thus, when applying the flexible reservation scheme like dynamic DRP and PCA reservation with traffic and priority aware reservation selection, a considerable performance gain can be achieved. In particular, when the arrival traffic increases, the dynamic DRP and PCA reservation scheme outperforms and delivers the maximum achievable throughput performance. With this result, it is inferred that the throughput of the system depends on the number of connected node, the amount of arrival traffic, and the employed reservation scheme.

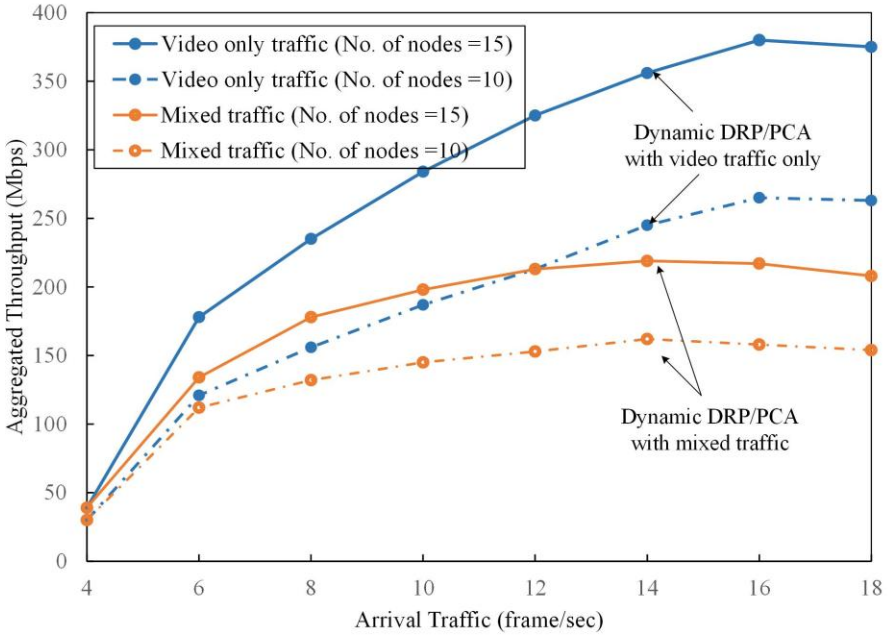

Figure 8. Aggregated throughput of the dynamic DRP and PCA allocation with shipboard control data traffic (mixed traffic).

Figure 8 shows the aggregated throughput of the dynamic DRP and PCA allocation protocol as a function of mixed video and shipboard control data traffic, comparing the case of video only traffic with the case of mixed traffic. Moreover, when it deals with shipboard control data that has a small size of frame but needs MASs as many as high-speed video frames, the throughput performance change is shown in Figure 8. Such an unbalanced packet size between video and shipboard control data leads to waste MASs in DRP hard region, since shipboard control data requires higher priority than video traffic. For this reason, the performance degradation by supporting mixed traffic can be observed in Figure 8. In our simulation, the number of nodes with shipboard control data is set to one third of the total number of nodes.

However, it is noted that the dynamic reservation method can achieve higher throughput performance than that of the strict reservation method. With the conventional strict DRP and PCA reservation approach, the system cannot achieve the even normal throughput because of the strict reservation and resource wasting traffic such as shipboard control data. Thus, it is concluded that the proposed dynamic DRP and PCA reservation with traffic and priority aware reservation selection can be applicable to a ship area network supporting high quality video traffic and high priority shipboard control data traffic as well.

5. Conclusion

This paper evaluates the feasibility of the dynamic DRP and PCA reservation protocols (based on WiMedia UWB ECMA-368 MAC) into a wireless gateway supporting mixed video traffic and shipboard control data traffic. It is shown that the dynamic DRP and PCA reservation scheme can guarantee high throughput performance to both high-quality video traffic and high-priority shipboard control data traffic with variable the portions of two data periods according to traffic load. Thus, it is concluded that the proposed dynamic DRP and PCA reservation with traffic and priority aware reservation selection is a very feasible option to a wireless ship area network supporting high-quality multimedia services on board and reliable instrument control information as well.

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