IJIBC 16-4-1

Dynamic Channel Allocation of WiMedia UWB MAC Protocol Supporting Mixed HD Video Data and Shipboard Control Data with Link Parameter Optimization

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Abstract

This paper considers WiMedia UWB network based wireless ship area network (WSAN) so as to support high-quality multimedia video data services and important shipboard control data. 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 support mixed high-quality video traffic and shipboard control data traffic applying varying DRP and PCA data periods according to channel condition and link parameter ptimization. It is shown that the proposed dynmaic channel allocation of WiMedia UWB MAC protocol can provide reliable mixed video and shipboard control data traffic as well.

Keywords: WiMedia, UWB, WSAN, ECMA-368, MAC protocol.

1. Introduction

The general ship area network architecture is generally organized as a single network with a backbone network comprised of three levels, i.e., instrument level, process level and system level, which is standardized by the international electro-technical commission (IEC). Navigational instruments are normally interconnected with the well-established IEC 61162-1 or IEC 61162-2 standards. These are based on standard asynchronous serial lines with a text message protocol, of which communication speed varies from 4.8 kbps up to 38.4 kbps. The conventional controller area network (CAN) of shipboard instruments based on IEC61162-3 standard and NMEA2000 supports up to about 50 nodes to share a common bus at 250 kbps. The conventional network hierarchy with the international standard is mainly based on wired networks such as dedicated connections, instrument networks, and shipboard control networks with Ethernet connection. This network delivers main operations such as sensing and control shipboard systems and management of crucial information for safety and navigation. These operations 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 effective maximum throughput of the navigational instrument's bus supported by the typical CAN connection is limited to 125 kbps. With this, a typical CAN cannot satisfy the increasing need for large amount of data transmission on board between a bunch of instruments and an integrated gateway. Besides control and navigational information between instruments devices, the need for various data services within a vessel is essential for a high-value added vessel. For this, a wireless transmission between devices (sensors) and a gateway is a reasonable option with respect to energy efficiency and system deployment cost.

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 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 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.

For high speed wireless transmission technology, WiMedia ultra wideband (UWB) MAC is a good option for wireless gateway, since it has been verified to satisfy the demand of multimedia video traffic services with high quality in a wireless home network environment [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 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 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].

Therefore, this paper focuses on dynamic channel allocation with both DRP and PCA MAC protocols into

a wireless gateway for WiMedia UWB transmission. This could deliver high quality video stream service as well as a bunch of shipboard control information data for a high value added vessel. This paper evaluates the performance 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. Moreover, this paper mainly proposes the optimization of such periods of two DCA and PCA data periods applying link parameters optimization algorithm.

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 channel allocation of WiMedia UWB MAC protocols applying link parameter optimzation. Section 4 shows the simulation results and discussion of the proposed approach, followed by the conclusion.

2. WiMedia UWB based Ship Area Network

2.1. Conventional Ship Area Network

The conventional shipboard data architecture by the IEC standard is the Maritime Information technology Standard (MiTS) project [4]. NMEA 2000 is IEC-accepted as a standard IEC 61162-3 on IEC technical committee 80, working group 6 (digital interfaces), and successfully develops another LAN (Local Area Network) standard for ships where LAN requires high capacity and also high security (IEC 61162-4). This was developed as an integrated ship control (ISC) protocol, which could integrate instrument networks (NMEA 2000) on the gateway with industrial data network in the automation system. This system will allow up to about 50 nodes to share a common bus at 250 kbps. Messages vary from 8 bytes up to about 1,000, but at an overhead of 50%. Thus, effective maximum throughput on the bus is about 125 kbps. Among four layers such as instrument, process, system, and administrative, at the instrument layer, instruments and devices are connected to a wired gateway. However, this cannot support sufficient data throughput caused by various instruments and devices, 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. 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.
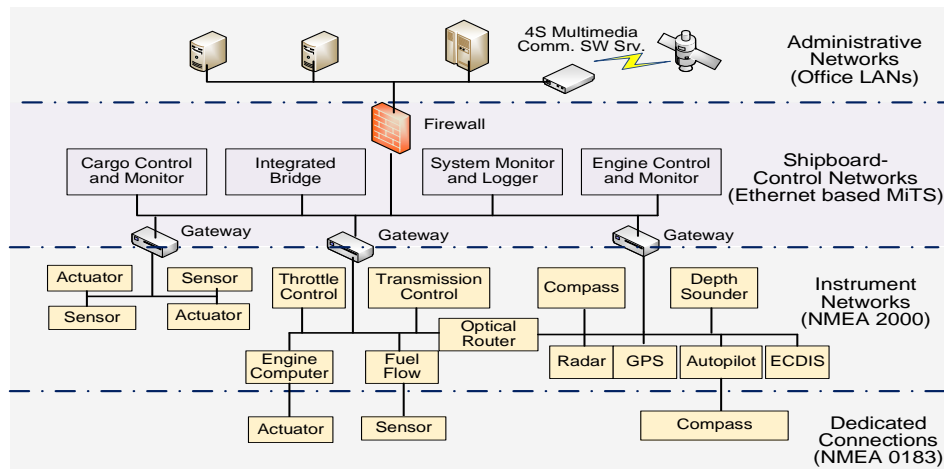
Figure 1. Conventional layered ship area network architecture based on international standards [4].

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.
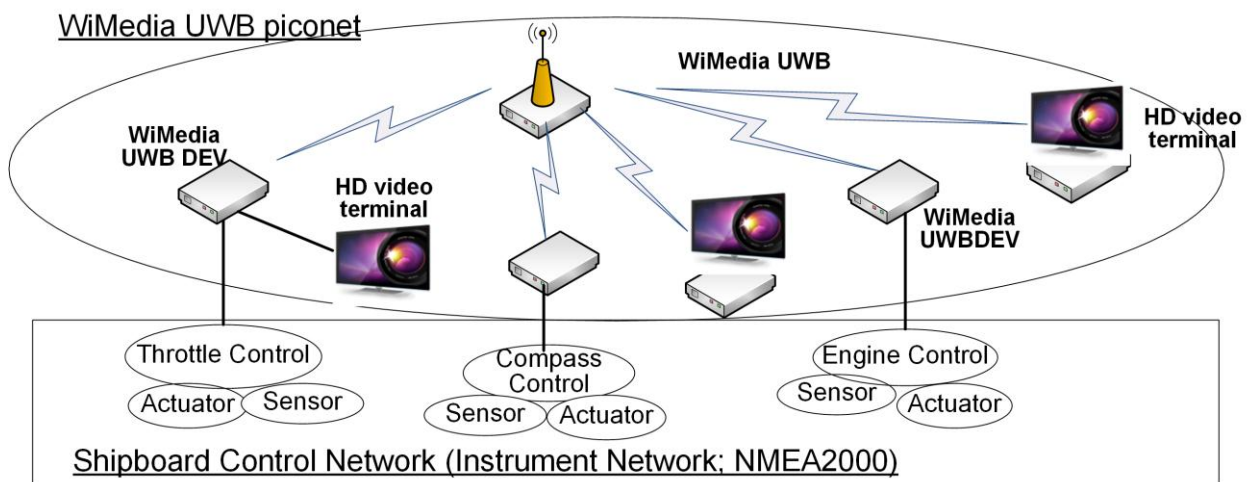

Figure 2. WiMedia UWB piconet model with mixed HD video data and shipboard control data.

3. Proposed Dynamic Channel Allocation with WiMedia UWB MAC Protocols for Mixed Data Traffic

3.1 WiMedia UWB MAC Protocols

In WiMedia UWB MAC based on ECMA-386, the channel time is divided into a time unit of a superframe, which 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. It 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 for 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 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.
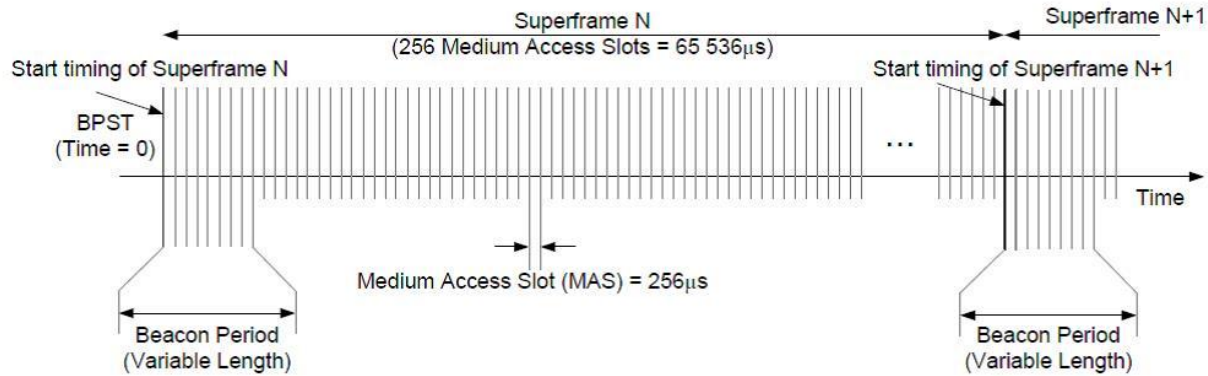
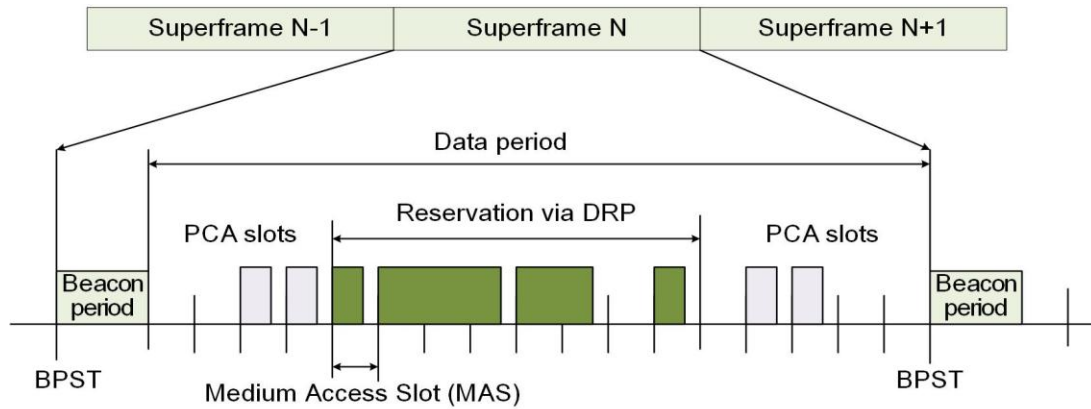**Figure 3. Structure of superframe WiMedia UWB (ECMA-368) MAC [2].**

Figure 4. Structure of DRP and PCA.

PCA in WiMedia UWB MAC 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 of traffic are defined, which are called voice, video, best effort, and background. The PCA procedures are applied by any devices for each access category to obtain a transmission opportunity (TXOP) for the frames belonging to that AC using the PCA parameters associated with that access category. 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. 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 Dynamic Channel Allocation with WiMedia UWB MAC Protocols Supporting Mixed Data Traffic

In this paper, we consider a dynamic channel allocation scheme, which combines both DRP and PCA

protocol for supporting HD-video data streams as well as shipboard control data. It is the dynamic combination of the reservation and contention-based MAC protocols. Also, it is note that DRP is suitable for real-time traffic with a constant bit rate, while PCA can support bursty traffic more efficiently. Shipboard control data traffic within the vessel carry control and status information. 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 as well as in this paper. The superframe considered in this paper is shown in Figure 5 where the data period of superframe is divided into two main parts such as DRP and PCA.
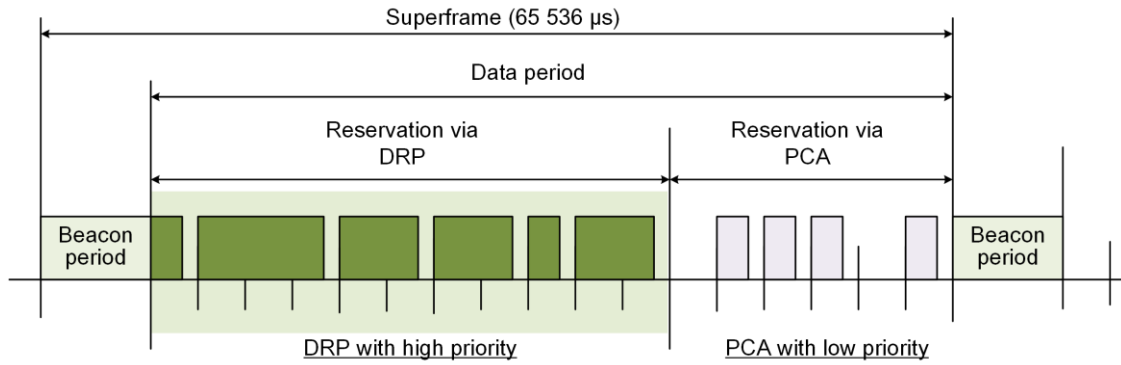

Figure 5. Structure of dynamic DRP and PCA reservation approach.

By the conventional approach, for HD-video data traffic, MAC reserve the MASs based on DRP and the PCA part are reserved for other low priority traffic. However, in this paper, we need to consider the shipboard control data traffic with high priority as well as channel link condition. 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.

This paper focuses on the maximizing of the achievable aggregated data throughput performance of the WiMedia UWB. It is most important to consider the link parameters such as link congestion measurement, HD-video data traffic measurement, shipboard control data traffic measurement and link quality measurement into channel allocation procedure. Thus, in this paper we propose dynamic channel allocation scheme as shown in Figure 6. As shown in Figure 6, we adopt the logical block of the link parameter measurement. Since we use a dynamic DRP and PCA reservation based on the link parameter condition and priority, we do not fix either DRP region or PCA region as shown in Figure 5.

In this paper, as shown in Figure 6, we use the optimization block at each superframe to estimate the link parameters of utility function, which is defined by $U(Lc(i), L_{\_HD}(i), L\_sh(i), L\_q(i))$. Based on this utility function, the decision of dynamic channel allocation at each superframe is carried out. And then, each number of MAS slots allocated to DRP hard, DRP soft and PCA allocated is decided at each superframe. We use link congestion measurement ($L\_q(i)$) is used as indicator of traffic load in each superframe and other link parameters such as link congestion measurement ($Lc(i)$), the prioritized HD-video data traffic

measurement ($L_{\_HD}(i)$) and the shipboard control data traffic measurement ($L\_sh(i)$). Based on these link parameters, the optimization procedure is performed by calculating and maximizing the utility function $U(i,k)$ and the estimated utility function $U(i)$ is as following:

$$U(i) = \frac{\sum_{k=1}^{K} M_k \times U(i,k)}{\sum_{k=1}^{K} M_k} \tag{1}$$

where $U(i,k)$ is the utility of superframe i for allocating MSA. It is noted that the decision on channel allocation is made based on $U(i)$. This channel allocation scheme is executed periodically. The WiMedia MAC protocol decides the appropriate portion of MAS slots, which is allocated to DRP and PCA based on the utility function value.
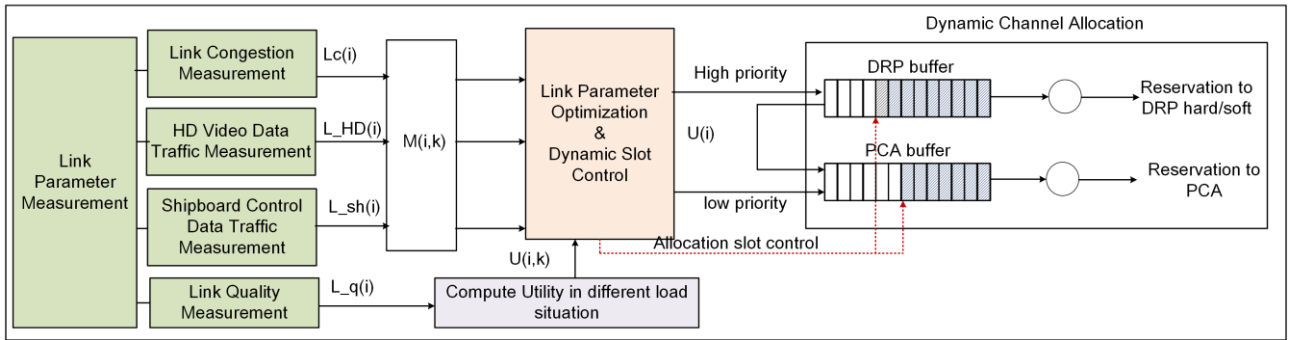

Figure 6. Dynamic channel allocation of DRP/PCA reservation based on link parameter optimization.

4. Simulation and Discussion

In our simulation, Matlab tool is used for the performance evaluation of the WiMedia UWB. We evaluated the aggregated data throughput of WiMedia UWB MAC in the mixed HD-video stream traffic and shipboard control data traffic with and without the link parameter optimization scheme. It is assumed that randomly 5, 10, 15 distributed devices (nodes) are connected to either shipboard instruments or HD video terminal. In our simulation, the number of nodes with shipboard control data is set to one third of the total number of nodes. 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 shows the aggregated throughput of the dynamic channel allocation scheme with link parameter optimization by dynamically varying 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 with and without link parameter optimization.

It is shown that 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. 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 7. The shipboard control data traffic with high priority is subject to waste MASs and results in degradation of data throughput.

However, it is noted that the proposed dynamic channel allocation with link parameter optimization scheme can achieve higher throughput performance than that of without link parameter optimization. Thus, it is concluded that the proposed dynamic channel allocation scheme with link parameter optimization with link traffic and priority aware reservation selection can achieve much higher performance gain. With the conventional DRP/PCA reservation approach, this gain could not be expected because of the strict reservation, variation of link quality, and resource wasting. Thus, the proposed scheme can be applicable to a ship area network supporting high quality video traffic and high priority shipboard control data traffic as well.
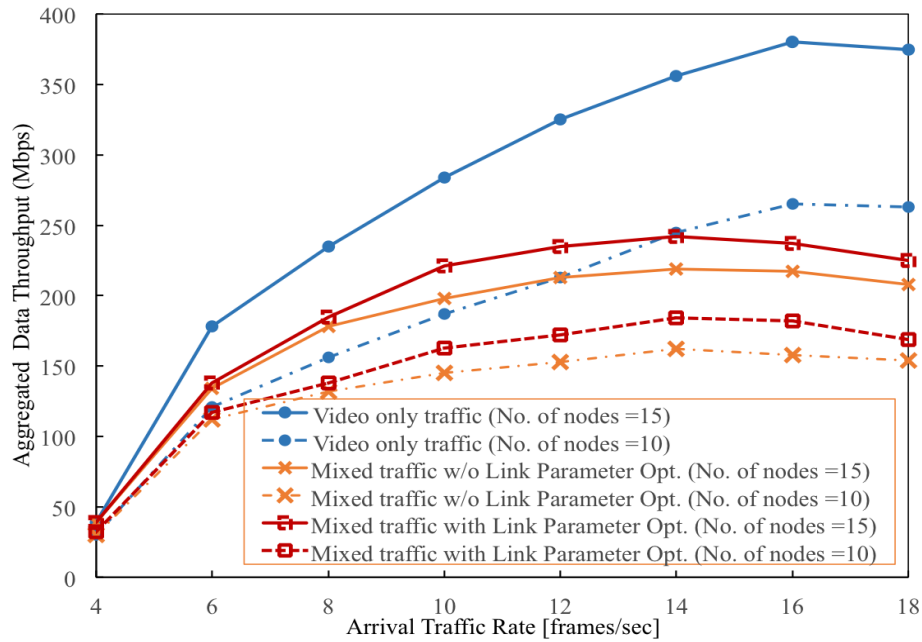

Figure 7. Aggregated throughput of the dynamic channel allocation with and without link parameter optimization for HD-video data traffic and shipboard control data traffic.

5. Conclusion

This paper evaluates the dynamic channel allocation by varying the portion of DRP and PCA reservation protocols dynamically in mixed HD-video data traffic and shipboard control data traffic. It is shown that the dynamic channel allocation with link parameter optimization considering link quality and traffic congestion can guarantee high throughput performance. Thus, it is concluded that the proposed dynamic channel allocation of DRP and PCA reservation with link parameter optimization 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.

Acknowledgement

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