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Survey on Research Advancements in WiMedia MAC protocol

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Abstract

WiMedia Alliance is an entity of personal area network occupying the large scale of real time applications with its attractive features like high data rate with low energy consumption. WiMedia Medium Access Control protocol is equipped in such a way that they can communicate with its counterpart to form a network. This enables advances in technology and availability to facilitate the extensive deployment of WiMedia network. But the overall performance of WiMedia network is limited due to factors like coverage distance, Interference, Mobility, Energy Consumption etc. So in this paper, we present the comprehensive survey of recent advancements in WiMedia Mac to provide a platform for a better consideration of WiMedia Medium Access Control research status to potential researchers and highlight the combined effect of WiMedia and other technologies.

Keywords: wireless personal area network, WiMedia MAC, review, distributed reservation protocol, prioritized contention access

1. Introduction

Wireless Personal Area Network (WPAN) aims to connect the devices within the radio range standardized under IEEE 802.15. In this era, huge numbers of protocols are available for home automation which is most essential for a better quality of time. Personal Area Network (PAN) protocols play a vital role in home automation, industry automation, building medical applications, military applications and so on. Hence this technology is becoming more popular, friendly, trustworthy, smart and powerful. WPAN is used not only for the interpersonal communication it is also capable in communicating with the next higher level network also.

Over the past decade, prominent technologist accepted WiMedia for Distributed Medium Access Control for developing their physical layer based on Ultra-Wide Band to a wide range of applications like wireless USB, IP based WiMedia network, Wireless 1394, Bluetooth and wireless TCP/IP. The main objective of WiMedia is to enhance high data rate connectivity for supporting multimedia applications and enrich the interoperability between devices in personal area network. WiMedia Alliance have developed technical specifications for physical and medium access control layers, architecture for coexistence, protocol adaption layer for IP, and IP based applications. WiMedia provides radio platform based on ultra-wideband using multiband orthogonal frequency division multiplexing (MB-OFDM). WiMedia MAC communicates with payload of maximum 1024Mbit/s and consumes low power with a supporting frequency of 3.1 to 10.6 GHz for multimedia data transfer. Various countries have allocated frequency spectrum with different constraint and imposed limitations on to the output power within the acceptable limit. UWB communications during coexistence detect a legacy channel without causing interference.

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WiMedia Alliance demarcated fourteen 500MHz bands, in each single band maximum of three non-overlapping channels. Two devices within the radio range communicate with the same frequency regardless of their logical channel. But it may be either noise to each other or logically share the timeslots in the channel. IEEE 802.15.3[3] uses centralized approach when the devices form a piconet controlled by Piconet Coordinator (PNC). PNC contains information about the participants of the piconet, manages using control information and the access is based on Time Division Multiple Access (TDMA). But the drawback of coordinated approach is the capacity of the coordinator, access and diversity, scalability, QoS provisioning, security. To address the issues related with coordinated access, a distributed MAC base on MB-OFDM is proposed by WiMedia Alliance and ECMA [1-2]. Both of these protocol provide slotted access using Superframe, where communicating devices needs to reserve slots using reservation protocols developed by WiMedia.

In the next section, overview of the WiMedia MAC is presented to understand the basics of the access mechanisms used in this protocol. In the later section, the contributions of various researchers towards the development of MAC protocol are explored.

2. Overview of WiMedia MAC

Superframe structure is of 65535 μs duration which is further decomposed into medium access slots with 256 μs shown in Fig. 1. In each superframe, WiMedia MAC supports transfer of control information using beacon period and data transfer after communicating beacon frames. Data transfer phase consists of two types of medium access techniques based on reservation using Distributed Reservation Protocol (DRP) and contention using Prioritized Contention Access (PCA) sequentially. WiMedia MAC supports two modes of data transfer namely: standard and bursty along with aggregated frames.

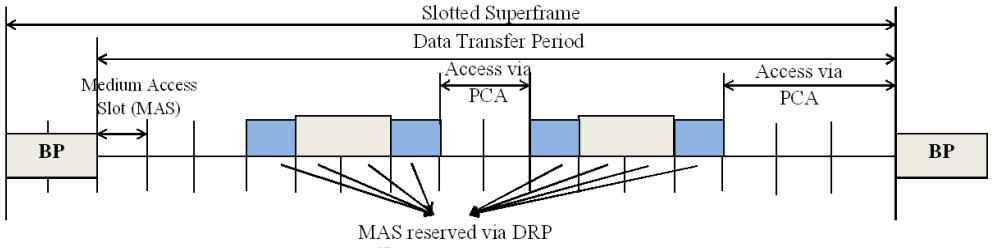

Fig. 1 Superframe Structure

Information discovery about a device in the piconet amongst the participants is done by either broadcasting beacon frames or requesting probe commands. Beacon Period starts with signalling slots for mSignalSlotCount slots limited by mMaxBPLength where Highest Occupied Beacon Slots [2 - 4] specifies the maximum utilized slots. The beacon frames are transmitted using these slots consecutively. Once the device is powered up, the device scans for at least two superframes. It creates a piconet using its own beacon and specifying the new Beacon Period Start Time (BPST). No device is allowed to transmit its beacon frame in the signaling slots. If it receives beacon frame while scanning then finds an appropriate free slots to transmit its own beacon. Beacon frames are used to convey device capabilities and slot occupancy. These can be used to avoid collision within radio range. These are conveyed using information elements denoted by IE. But in this article the discussion is limited to the IEs related to the requirement of MAC scheduling: BPOIE, PCA Availability IE, DRP Availability IE, Distributed Reservation Protocol (DRP) IE, Link Feedback IE [2]. Beacon Period Occupancy IE (BPOIE) is used to provide information about neighbor's BP occupancy in the previous Superframe. PCA Availability IE indicates the list of MASs in which a device is available to receive PCA frames and will be able to transmit the required response. DRP availability IE indicates a device's availability for new DRP reservations. Distributed Reservation Protocol (DRP) IE indicates a reservation with another device. Link Feedback IE provides data rate and power control feedback about the device.

DRP enables two methods of registration: 1) explicit registration, using DRP reservation request and response frames. 2) Implicit registration, using DRP IE in beacon frames. Using DRP, various restrictions were imposed onto the registration namely: Hard, Soft, Private, PCA and Alien BP. Hard and Soft DRP indicate that the owner of the registered slot will be able to use these slots and they will not be shared with other devices. PCA enables the user to access the medium through PCA mechanism.

PCA is an extended version of IEEE 802.11e EDCA. It provides medium access based on CSMA/CA and ensures the restrictions for the devices using Contention Window grounded by Access Category considering priority of data. For the transfer of data frames basically eight priority levels are defined under four access categories [2]. A device may give up the medium only when reservation block is in use under DRP based registration. For using PCA mechanism a device needs to maintain Network Allocation Vector which indicates the residual/idle time of neighboring devices. The parameters used by PCA are Arbitrary Inter Frame Space (AIFS [AC]), minimum and maximum congestion window (mCWmin [AC] and mCWmax [AC]) for setting backoff counter, and limited by Transmission Opportunity (mTXOPLimit [AC]). The timing for the entire set of parameters may vary according to access category shown in Fig. 2 [2].

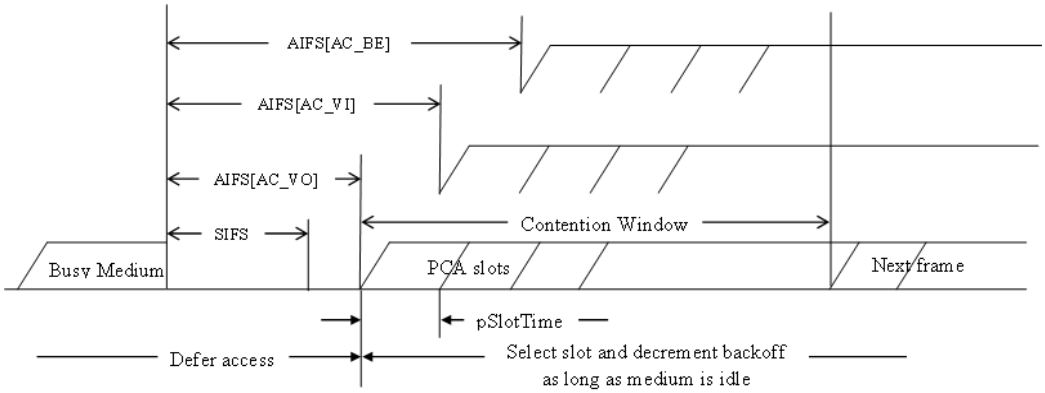

Fig. 2 IFS timing relations

3. Research Advancements in WiMedia MAC Protocol

There are enormous amount of work carried out by various research groups to enhance the performance of WiMedia MAC. But the main focus of this article is analyzing the research trends using DRP and PCA. In this section, the progress of research is organized in terms of optimizing the resource allocation for different stream of data with respect to contention, energy consumption in distributed nature. As a result, few models have been presented for the betterment of WiMedia MAC and the researcher's contributions to enhance Quality of Service are highlighted in Fig. 3.

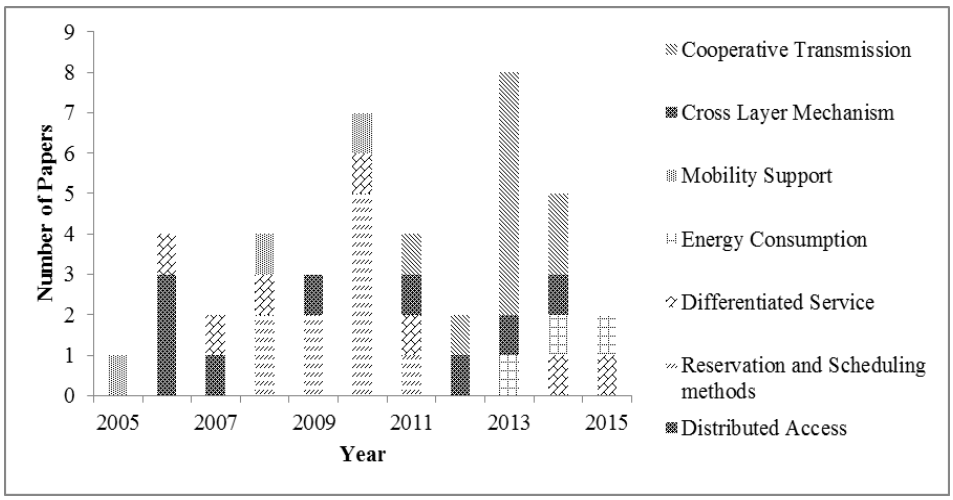

Fig. 3 Number of Publications in WiMedia MAC's QoS

3.1. Distributed Access Network

In this medium access method, a node listens for at least two Superframes before transmitting its beacon frames. Once a beacon is detected, the concern node synchronize itself in the Superframe using freely available slots, otherwise it creates its own Superframe. For a node creating, joining or leaving the network may result significant power consumption. If the target device moves, then it may come across multiple piconet. Therefore, a device may be forced to handle different BPST. Therefore, multiple superframes can be merged to minimize power consumption, hence increases reliability during a node's mobility. So changes in the existing network like new node joining the network needs BP extension protocol and while members leavies it need BP contraction protocol, hence power consumption during the aforementioned cases will be more. WiMedia MAC uses distributed approach to enhance reliability, to support mobility [5], to resolve collision and it uses collision resolution protocols [6]. Merging superframes also reduces the beacon length and thereby reduces listening period which in turn reduces energy consumption.

Basic properties of MAC includes Medium sharing, Organization of the network, Quality of Service aware call admission control, Scheduling methods various traffic flows, Optimization of power consumption. The importance of addressing Quality of Service in MAC layer is to support the time sensitive and real time data traffic by adopting a suitable behavior for meeting the user requirements.

3.2. Reservation and Scheduling for Various Traffic Flows

WiMedia Superframe is divided into Medium Access Slots (MAS) of $256\mu s$ duration. They are further grouped into zones, consist of 16 MASs hence zone based registration is adopted. Zone 0 is meant for beacon transfer so reservation is not accepted. A device should follow the constraints while registering:

- May prefer continuous slot within the limit starting from the First MAS number.
- May use DRP IE to request and/or release the slots

For an effective medium utilization or to reduce power consumption, a device may prefer lower MAS number so that the number of MAS allocated can be maximized [12 - 13], which is not enough to satisfy the Quality of Service requirements. Analysis on PCA mode of access shows that it is highly sensitive to frame payload w.r.to various access categories [10]. So the lesser frame length could result a better throughput. Service Interval may also be used to enhance the bandwidth utilization [11] in order to optimize the bandwidth and queuing delay. WiMedia Alliance is considered to be one of the highly efficient protocols for home networks. Since its performance is limited w.r.to distance, preferring the closest node will be helpful for avoiding interference; otherwise, Multihop approach may support to extend coverage distance further [35].

In WiMedia MAC, the data is divided into four groups: Background, Best effort, Video and Voice. Among these Voice is having highest priority compared to back ground data having minimum congestion window and shorter arbitration interframe space. As such no efficient resource allocation algorithm is available to guarantee QoS metrics. Therefore, dynamic resource allocation algorithm using efficient traffic predictors [13 - 14] are considered for resource allocation. Otherwise at node level, buffer utilization may be preferred so that if the reserved MASs are not enough to complete the data transfer, but it can be continued using PCA mode [16]. Researchers identified signal strength using beacon frame. Hence, interference free MAS reservation can be made to avail single or contiguous slots to increase the bandwidth capacity [17]. Using multi-level buffer may augment the medium utilization and reduce contention [18]. Isozone-fit algorithm elects slots nearby service interval to the flow's tolerable delay and examines superframe beginning with that zone for obtainable slots, keeps symmetric and well-structured superframe.

Table 1 Recent Advancements in Resource Allocation

Year	Author(s)	Solutions
2008	Zeng, Liaoyuan, Eduardo Cano, and Sean McGrath.	PCA mode is sensitive to nature of the data
2008	Xu, Yanfang, et al.	Time intervals may be utilized in an effective manner
2009	Kumar, Ashwini, et al.	Suitable for creating home networks
2009	Kuo, Wen-Kuang, and Chun-Yang Wu	Appropriate choice of MAS is important to maximize bandwidth
2010	Hu, Chunyu, et al.	Traffic prediction methods can be used to increase bandwidth allocation
2010	Zhang, Ruonan, Rukhsana Ruby, Jianping Pan, Lin Cai, and Xuemin Shen	Using PCA mode of access if DRP could not meet the requirement
2010	Rosier, Holger, Jens Frerichs, and Sebastian Max	Choice of interference free link could optimize channel utilization
2010	Zhang, Ruonan, et al.	Multi-level buffers may reduce the loss of data during contention
2010	Daneshi, Maryam, Jianping Pan, and Sudhakar Ganti	Flow from same MAS in every zone may reduce wait time
2011	Joo, Yang-Ick, and Kyeong Hur	Pre-emptive resource allocation

The data flow starts at the same row of different columns meets QoS requirement for video streaming [19]. Simultaneous transmissions may be coordinated to elude inter symbol intervention amongst successive contiguous transmissions. Priority based pre-emptive scheduling for QoS support resource allocation policies may be used to support prioritized QoS traffic in the MULTI USER MB-OFDM [20].

3.3. Service Differentiation

Quality of Service is generally measured as enactment of network qualified by the users. To measure QoS, several aspects of the network services are often considered to be error rates, packet loss, bandwidth, transmission delay, availability, Jitter, etc. As mentioned earlier to ensure the QoS WiMedia adopts access category based on the type of the network traffic, priority level varied for different data traffic. Also, when a device register using DRP, latency period experienced must be less than 4 milliseconds. When multiple devices are connected, there is a possibility of experiencing delay [6]. So permitting rapid data transmission or acknowledgement at upper layers may diminish delay and enrich the throughput of the system. By empowering MAC layer to acknowledge for TCP segements, Fast TCP ACK-Clocking (FTAC) scheme is able to meet the upper bound of the throughput. FTAC also supports interoperability between the UWB devices thereby it is able to satisfy the requirement of high quality multimedia streaming applications [8]. WiMedia cannot calculate and allocate fair resources and adapt current traffic load. In addition, it does not guarantee traffic specific quality of service parameters for various data streams. Real time data traffic is highly prioritized amongst all the other network traffic [20 - 21]. To avoid reservation conflicts, 2-hop neighbor information may be used [15]. Concurrent transmissions should be synchronized in order to avoid inter symbol interference between consecutive adjacent transmissions [23].

3.4. Energy Consumption

Energy dissipation will be more in centralized MAC layer protocols compared to distributed protocols. But those protocols rely on standard source of power. A comparative study says that, when compared to other local area network protocols supporting high data rate WiMedia consumes less power. But still an optimal algorithmic approach adopted may reduce the power consumption like Hard DRP reservation and flipping between soft and hard reservation [29] may be permitted through proper planning. When devices are idle WiMedia supports hibernate mode, so target device may inform its neighbors about its awake period [32] so the time spent for scanning regular beacon may be avoided. Interference or loss of signal strength plays a major role in consuming energy which may be avoided by comparing average RSSI and upper bound RSSI (e.g. 3.5 for 53Mbps) and adopting the suitable data rate for concern RSSI [34].

3.5. Mobile Support

Since personal area network coverage region is limited, changes in topology are induced by node movement. It possesses chaotic arrangement, restricted energy sources, movement of nodes leading to weak signal strength or interference. In addition, nodes sharing the same medium limit the frequency spectrum. But the performance may be limited by the aforementioned reasons; consumption of resources, power, and network lifetime even affects the throughput. Devices within two-hop range should use different beacon slot, enables spatial reuse of beacon slots. Due to mobility devices with the same BPST may be in radio range of each other. In such case to avoid collisions BP needs to sorted and merged with the alien devices. BP Switch IE is used to communicate the information related to new beacon period occupancy slot [4]. To enhance the utilization of MAC relay based transmission in widely supported based on parameters like low energy, high interference, restriction in coverage area etc.,. Choosing the relay node should annoy these issues and data rate supported by the relay is the major factor. Relay based transmission supports higher network life time, low power consumption, higher throughput, and nominal delay [7]. Multihop route between source and destination is adopted and some authors inherit priority to differentiate real time traffic [15].

3.6. Cross Layer Mechanism

A cross layer mechanism considering the user requirement based QoS metrics strengthen the error rate and enhance the performance. By reading error rate, Link layer communicates with the application layer so as to optimize the payload length in order to reduce the error rate and delay [22]. Quality of Service might depend on two factors namely: Service rate allocated and Requested rate and their corresponding ratio i.e Quality of Service satisfaction ratio. A link's instability can be identified by using Link Feedback IE or Receiver Signal Strength Indicator. Compared to neighbouring nodes, if the destination node signal strength is low, and then using SoQ ratio relay nodes are identified [20] and Rate Adaption IE are used to optimize the performance.

3.7. Cooperative Transmission

Studies on transmission of video streams on UWB networks shows that bandwidth capacity beyond 200Mbps could not sustain packet loss rate and therefore results increased retry limit [9]. But the contention may be resolved using MAC capability IE [21], a specific format for addressing Traffic which is used to control Contention Window. If collision occurs, then Contention Window value is modified, which reduce delay and improve throughput.

Table 2 Recent Advancements in Cooperative Transmissions

Year	Author(s)	Solutions
2011	Park, Hyunhee, Sangheon Pack, and Chul-Hee Kan	MAC Capability IE to represent the traffic
2012	Joo, Yang-lck, and Moon Kyu Kwon	GetMasAvailability IE to identify free slots
2013	Hur, Kyeong, Won-Sung Sohn, and YangSun Lee	To avoid bad channel conditions prefer better link quality
2013	Kim, Jin-Woo, Yugyeong Huh, Yeon Woo Lee, Se Yeong Maeng, S. H. Park, K. Hur, and Seong Ro Lee	Traffic Indication Map for PCA Traffic
2013	Joo, Yang-Ick, and Kyeong Hur	Relay Selection Procedure for better
2013	Kim, Jin-Woo, Kyeong Hur, and Seong-Ro Lee data rate	Cluster based approach for resource reservation
2014	Lee, S., Yeonwoo Lee, and S. Lee	Relay Selection Procedure for better data rate

When multiple nodes try to access the medium, it may lead to contention. So to avoid resource reservation conflicts and bad channel conditions, cross-layer link adaptation is preferred [26]. Another method of addressing contention is via Traffic Indication Map Information Element [27] with PCA traffic to reduce power consumption. To minimize the possibility of data frame collisions, address channel instability change in the data rate may be preferred, hence Channel Change IE [32], Relay selection using high data rate [28]. However, prior to registration, authors proposed GetMasAvailability IE [25] to identify the free slot to deliver conflict free reservation and enhancement using cluster based reservation [31]. Then, the throughput of the system is unsteady but cluster based reservation might influence it and reduce the latency. Error rate may be high due to the interference,

so researchers contributed towards identifying interference free communication and good signal strength [24]. Researchers identified that WiMedia MAC is suitable for health care and hence presented compatible architecture for Body area network [30]. The communication may also be affected by few more issues like congestion, fault nodes and so on [36]. To ensure reliable communication, congestion control problems can be addressed using relaying mechanism effectively.

4. Discussion and Conclusion

IEEE 802.15.3 support wireless connectivity for multimedia data transfer in personal area networks. Based on recommendations from various industries, with appropriate approval WiMedia presents its customized versions wireless USB and high speed Bluetooth. This technology attracts many vendors and hence WiMedia Alliance promotes the development of these products with respect to IEEE 802.15.3 specifications.

So in this review, we have presented the assessment of contemporary research advancement in both the single hop and multi hop based architecture for WiMedia MAC. WiMedia MAC supports peer to peer networking satisfies and proved to be an extended version of IEEE 802.11e MAC. Research contributions related to resource reservation are investigated and identified limitations are resource provisioning schemes have to provide space for handling numerous requirements with varied bandwidth with less waiting time. Complications may arise while addressing mobility or merging multiple piconets like energy efficient beacon contraction, frame collisions and cooperative transmission to support multi hop architecture.

The resource reservation may have an appropriate procedure which considers a balanced mode including Hard and Soft DRP, PCA. A successful resource allocation should not affect the Quality of Service through any mean. But it is a challenging task for a researcher to assure Quality of Service under mobility, congestion or Multihop scenarios. According to the survey carried out, the existing state of art provides fair allocation of resource, hence in this work few suggestions were made to minimize the issues. Since WiMedia provides good bandwidth more researchers are showing interests towards its development.

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