A resource preserved MAC protocol for QoS provided UWB ad hoc networks

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Abstract: This paper proposes a resource preserved medium access control (MAC) protocol which provides Quality of Service (QoS) support for multimedia applications in ultra-wideband (UWB) ad hoc network. The proposed protocol accounts for the UWB unique characteristics while considering the QoS requirements. The evaluation results in throughputs, end to end delay, power consumption and power utilization show that, the proposed algorithms achieve a balance work between the throughputs and power consumption.

Keywords: UWB, MAC, resource allocation, QoS

1. Introduction

Nowadays, more and more applications in network have concerned the problem of QoS. For instance, some kinds of streaming multimedia transmission in short range or video teleconferencing (VTC) regard throughput and latency as very important parameters. On the other hand, power consumption is also a big problem of all wireless networks. Compared with the other wireless transmission technology, such as WIFI and Bluetooth, ultra-wideband has significant high-transmission data rate and low power characteristics in short range. Hence, UWB has the potential to become the best solution for the wireless personal area network (WPAN).

The physics (PHY) layer issues for UWB in WPAN environments have been extensively studied in recent years. However, the problems related to the medium access control (MAC) techniques remain largely unexplored, especially regarding the targeted ad hoc networking scenarios. In ad hoc networking, the devices are interconnected via spontaneously created, disposable connections, without relying on a pre-existing infrastructure. These scenarios pose seriously challenging research tasks, since the same medium should be used by many mutually interfering WPANs under the stringent synchronization conditions imposed by the IR-UWB. In these cases, the MAC layer design becomes the most important issue. And for UWB MAC design, one major challenge is the QoS provisioning with efficient resource utilization.

In this paper, we focus on the resource allocation mechanisms to provide QoS with low power and propose a resource preserved MAC protocol.

2. Relative works

In [1][2], a power control (PC) mechanism is proposed and developed. According to the analysis provided in these papers, the capacity for UWB network is bounded by the signal to interference and noise ratio (SINR) threshold given by:

$$SINR = \frac{P_i G_{ij}}{R_i \left(\eta_{ij} + T_f \sigma^2 \sum_{k=1, k \neq i}^{n} P_k G_{kj} \right)} \geq \gamma_{i,j}, i, j = 1, ..., N \quad (1)$$

Here,

R_i :binary bit rate of the ith link;

P_i : average power emitted by the ith link's transmitter;

G_{ij} : path gain from the ith link's transmitter to the ith link's receiver;

η_i : background noise energy plus interference from other non-UWB systems;

σ^2 : a parameter depending on the shape of the monocycle;

T_f : pulse repetition time;

$\gamma_{i,j}$: the SINR the threshold.

In order to achieve successful transmissions, we should maintain the receiver-side SINR ratio over this threshold. This kind of power control mechanism needs a smallest threshold so that, it can guarantee the corrected transmissions when the channel condition is poor. If the channel condition becomes better, the transmission is still at a low speed level. That means the throughputs of the network is very low.

In [3][4], rate control (RC) protocol has been discussed. From the statements in these papers, the interference caused by concurrently transmitting nodes is approximated with a Gaussian white noise. Therefore, the total noise is the sum of the background noise and all the interfering signals, and is also Gaussian. Then, the data rate can be thought linear with the SINR of the link, which can be seen as follow:

$$R_A = K \cdot SINR_A \quad (2)$$

Here K is a constant. RA and SINRA are the transmission rate and SINR of link A respectively. With the increasing of the transmit power, the data rate and throughputs also increase rapidly. But the utilization of power becomes poor, because of the large consumption of power. Hence, we should make a tradeoff consideration between the PC and RC protocol for QoS guarantee.

3. Proposed MAC protocol

In this section, the proposed resource preserved MAC protocol is given out and the multiple access mechanism is analyzed after that.

3.1 Resource allocation algorithm

In order to contribute such a QoS sensitive MAC protocol, every node in the network should obey two conditions to reduce the interference to the other nodes.

i). A sender should not undermine the receiving of its neighbor node.

ii). A receiver should leave the margin for the neighbor node's sending, so that, this receiving will not be disturbed by the neighbor nodes' sending.

We assume that the number of the link is NT, the rate required by the QoS of each link is R_{req}, and the highest power of each link is P_{max}. As mentioned in Section 2, the tradeoff between PC and RC is necessary. So, for my proposal, the protocol will provide the data rate which required by the QoS of each link and will also transmit in lowest power consumption. Then, the following equation should be met,

$$\begin{cases} \dfrac{P_i^T G_{ij}}{R_i\left(\eta_{ij}+T_f\sigma^2\sum\limits_{k=1,k\neq i}^{N_T} P_k{}^T G_{kj}\right)} \geq \gamma \\ \dfrac{P_i^T G_{ij}}{\gamma\left(\eta_{ij}+T_f\sigma^2\sum\limits_{k=1,k\neq i}^{N_T} P_k{}^T G_{kj}\right)} \geq R_{req}, i=1,...,N_T \\ 0 < P_i^T \leq P_{\max} \end{cases} \quad (3)$$

Since there is no center control unit in such a distributed network, great challenges exist to provide QoS for the different operations. When QoS is required for one link, the QoS provision of others links will be surely interfered by this link. At the same time, the information of the whole network is limited for one node. That will bring the difficulty for resource allocation. From these two points of view, we develop a resource allocation protocol, which is named resource-preserved, to solve the problem. In our proposal, every new link will preserve the resource of channel by prediction. It estimates the interference of other future links. If the preserved resource is not utilized in this link, it will be released when the link is finished. So, Eq (3) can be rewritten into Eq (4).

In section 3.2, we present a practically feasible, distributed, balance solution of the optimization problem mentioned in this section for QoS traffic (power minimization) and for BE (Best effort) traffic (throughput maximization).

$$\begin{cases} \dfrac{P_i^T G_{ij}}{R_i\left(\eta_{ij}+T_f\sigma^2\sum\limits_{k=1,k\neq i}^{N_T} P_k{}^T G_{kj}+N_{est}\right)} \geq \gamma \\ \dfrac{P_i^T G_{ij}}{\gamma\left(\eta_{ij}+T_f\sigma^2\sum\limits_{k=1,k\neq i}^{N_T} P_k{}^T G_{kj}+N_{est}\right)} \geq R_{req}, i=1,...,N_T \\ 0 < P_i^T \leq P_{\max} \end{cases} \quad (4)$$

Where:

$N_{est} = t_l \times T_f \sigma^2 P_{ij}{}^T \overline{G}_{est}; P_{ij} = P_i; \overline{G}_{est} = G_{ij}$

t_l : *transmission time of i - j link*

3.2 Multiple access mechanism

In this section, we propose a unique multiple access mechanism for both BE and QoS traffic. Since the implementation of the minimum power solution would require a complete reconfiguration of powers to adapt to every net work change due to new accesses or release, the existing solutions can hardly accomplish this task. In this paper, a different solution which requires a margin for the minimum power is proposed. It aims at avoiding reconfigurations and being easily realized in the distributed environment.

In the case of both BE and QoS traffic, the proposed solutions are based on local measurements and signaling, achieving a tradeoff between signaling load and accuracy of the optimization. In this work in particular, we adopt a step-by-step approach: we assume links are active and a new link requests to join in. Then, the aforementioned problems are solved in order to decide whether the new link is admissible and which is the (best) bit rate and/or power level for it.

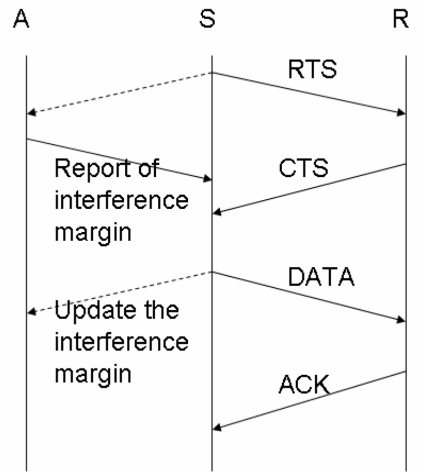

Fig.1 Signaling procedure for BE and QoS traffic.

We discuss the case of a UWB terminal wishing to start a new link. In Fig.1, node S is the sender, node R is the receiver and node A is represented for the neighbor receivers. The overall scheme is composed of following key steps:

Step 1) node S contacts node R to notify its intention to start a communication at a given rate, this signaling (RTS) is also heard by S's neighboring receivers which in turn is triggered to signal its interference margin (IM); this represents the signaling phase. Obviously, if other receivers are in S's MAC domain, they are also requested to answer giving their IM.

Step 2) node R measures the perceived interference and notifies the relevant result to S in CTS signal; this is a measurement phase.

Step 3) node S has now acquired all the information needed to check the access rule, and can, thus, perform the access check phase. In short, A computes $P_{allowed}$ on the basis of the IM values and of the interference. The fulfillment of condition means that a transmission power exists which is compliant with the requirements of the other links and simultaneously allows the new link to acquire a positive IM, given the required rate and the target SINR.

Step 4) The final phase is the ACK signaling, during which a confirmation handshake is performed by S and R. This acknowledgment implies also the update of the IMs of the already active links; this is performed on the basis of new measurements. As the transmission from S to R starts, R, as a new receiver, also computes the amount of its IM.

With reference to the access procedure, a specific implementation issue is concerned with the channels supporting signaling. The signaling procedure considers multichannel air interface to be a fact, since it must support concurrent active links which will interfere each other.

4. Simulation results

The simulation works in NS-2 environment. The PHY layer is based on the proposal in [5]. We have simulated an area of 10m×10m with 4, 8, 16, 24 and 32 nodes randomly distributed respectively. We show the setting of parameters in Table.1. The channel model is the default wireless channel in NS-2. In the simulation, we compare our proposal with RC and PC protocols in order to evaluate the performance.

Table.1 Parameter setting

Spread Spectrum	Time-hopping
Modulation:	PPM
Propagation model:	Tarokh
Pulse repetition time: T_f	100 ns
Dimensional parameter pulse: σ^2	1.99×10^{-3}
Background noise energy: η	2.58×10^{-21}
SINR threshold: γ	6 dB
Maximum Power: Pmax	0.56mw
Path gain constant: α	4
Number of mobile nodes	4,8,16,24,32
Size of the area	10m×10m

4.1 Power consumption

Power consumption of three protocols is shown in Fig.2. In this figure, the proposed protocol is only about 5% higher than the PC protocol. On the contrary, the RC protocol consumes a lot of power, especially with the increase of the number of node.

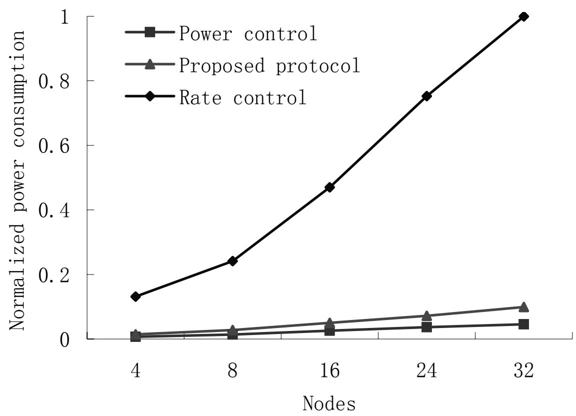

Fig.2 Normalized power consumption of different number of nodes compare with PC and RC protocol

4.2 Throughput

The simulation result of throughput is shown in Fig.3. Throughput can be defined as Eq (5),

$$THR = \frac{1}{T}\sum_{i=0}^{n} R_i \Delta t_i \qquad (5)$$

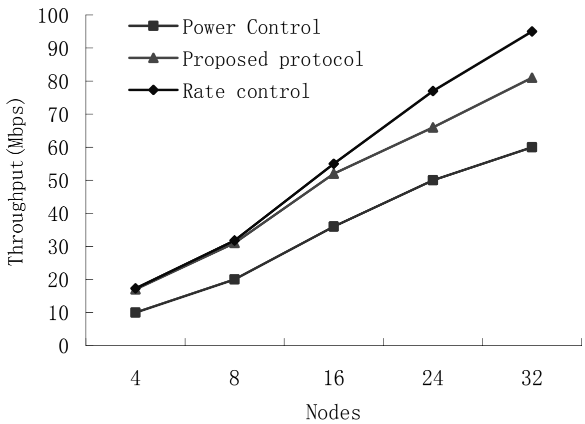

Fig.3 Throughput of different number of nodes compared with PC and RC protocol

With the increase of the number of nodes the Throughput is also going up. The proposed protocol gains 36.7% ~ 65.9% higher in throughput than PC protocol.

4.3 End to end delay

End to end delay is mostly depended on the data rate of transmission. We can see the result of end to end delay of three protocols in Fig.4.

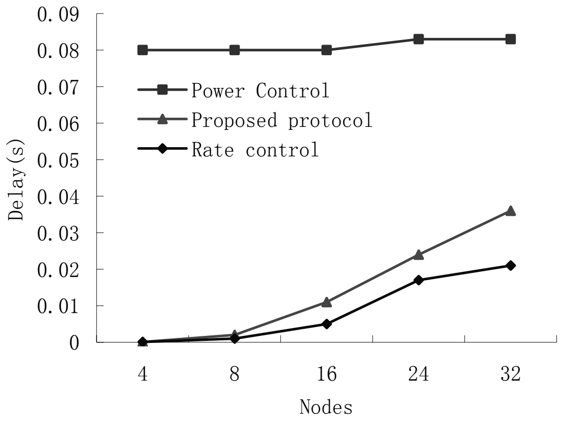

Fig.4 End to end delay of different number of nodes compare with PC and RC protocol.

From the simulation, more than 60.9% improvement is achieved in end to end delay compared with PC.

4.4 Performance for different QoS level

There are 7 QoS levels which are defined by ITU (International Telecommunication Union). As can be seen in Table.2, level 0 is a best effort traffic. With the increasing of QoS level, the traffic needs more bandwidth, less latency and jitter. The simulation chooses 4, 16, and 32 nodes and the result is shown in Fig.5.

Table.2 QoS priority level given by ITU

Priority Level	Traffic Type
0	Best Effort
1	Background
2	Standard (Spare)
3	Excellent Load (Business Critical)
4	Controlled Load (Streaming Multimedia)
5	Voice and Video (Interactive Media and Voice) [Less than 100ms latency and jitter]
6	Layer 3 Network Control Reserved Traffic [Less than 10ms latency and jitter]
7	Layer 2 Network Control Reserved Traffic [Lowest latency and jitter]

In Fig.5, the calculation of power utilization is shown as Eq.6.

Power utilization = Throughput/Power consumption (6).

The curves can be divided into two parts: A and B. In part A, the curves are nearly linear down, since with the increase of QoS level, the growth rate of power consumption is higher than that of throughputs. On the other hand, in part B, the curves become to concave. We find that when the QoS level is higher than 4, some access requirement will be rejected by the scheme. So this reduces the power consumption of signal transmission because the power consumed by the handshake signal is much less than the signal transmissions. Also, the throughput is nearly at the maximum level. Then in part B, the power utilization values decrease slower than that in part A.

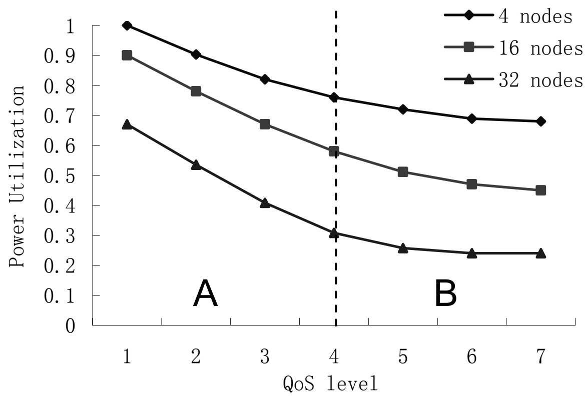

Fig.5 Power utilization for different QoS level

5. Conclusion

In this paper, we propose a resource preserved MAC protocol with both resource allocation and multiple access algorithms. From the simulation results, we can see that the power consumption of my proposal is about only 5% higher than PC protocol, but it provide 36.7% ~ 65.9% increasing in throughput and low latency. Hence, the proposed MAC protocol does a great balance job in power consumption, throughput and end to end delay between PC and RC protocol.

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