A Novel MAC Protocol for High Rate UWB Network

N. El-Fishawy, M. Shokair, and W. Saad
El-Menoufia University, Faculty of Electronic Engineering, Communication Department
Email: nelfishawy@hotmail.com, {i_shokair, waleedsaad100}@yahoo.com

***Abstract*— In this paper, a protocol is proposed in high data rate Ultra Wide Band (UWB) network to enhance the network performance and increase its capacity. This enhancement comes from the using Wise Algorithm for Link Admission Control (WALAC). Comparisons between proposed protocol, Slotted Aloha and Packet Reservation Multiple Access (PRMA) are done. The proposed protocol shows better results in both data traffic and streaming data (like internet) than others.**

***Index Terms*— Ultra Wide Band, Medium Access Control, resource allocation, Slotted Aloha, and Packet Reservation Multiple Access.**

I. INTRODUCTION

UWB transmission is an emerging technology for future wireless communications. The signal in this transmission can be defined as any signal having a fractional bandwidth greater than 0.20, or bandwidth is at least 500 MHZ [1]. The fractional bandwidth is a -10dB bandwidth of at least 500 MHz. The Federal Communications Commission (FCC) has allowed unlicensed use of UWB devices in the 3.1-10.6 GHZ frequency band with power spectral density -41dBm/MHZ [2]. UWB systems transmit a train of impulse radio (IR) waveforms with a nanosecond width, resulting spreading the power to several GHZ in the frequency domain. Therefore UWB signals are very low transmission power and hence very hard to be detected. Furthermore, low interference with the existing narrow and wide band systems. Due to the short pulse width, the UWB can reject the multipaths and support non line of sight.

Multiple Band Orthogonal frequency-division multiplexing (MB-OFDM) and Direct Sequence- UWB (DS-UWB) were proposed for the physical layer in IEEE 802.15.3a Task Group [3], [4]. The 802.15.3 Medium Access Control (MAC) mainly works within a piconet which is a small network [5], [6]. It consists of data devices and one of them is taken as the piconet coordinator (PNC). The PNC is responsible for devices association/disassociation and the basic timing of the network by sending the beacon to all devices [5].

In this paper, we propose a new protocol for high rate UWB channel in the piconet. This proposed protocol is based on using a novel algorithm for link admission named WALAC. This proposed protocol shows better performance when compared with Slotted Aloha and PRMA protocols.

The paper is organized as follows; Section II gives an overview of UWB physical model and the resource allocation. Section III introduces the detail description of the proposed protocol. Simulation results and the comparison discussions between Slotted Aloha, PRMA, and the proposed protocol are shown in Section IV. Finally, Section V shows the paper conclusion.

II. UWB PHYSICAL MODEL

The channel capacity for UWB is bounded by the Signal to Interference pluse Noise Ratio (SINR) threshold which is given by:

$$SINR = \frac{P_i g_{ij}}{R_i \left(\eta_i + T_f \sigma^2 + \sum_{k=1,k\neq i}^{N} P_k g_{kj} \right)} \geq \gamma_i \quad (1)$$

where P_i is the average transmitted power for the link i , g_{ij} is the path gain from the transmitter i to the receiver j which can be calculated as $d_{ij}^{-\alpha}$ where α is the path gain constant usually between 2–4 and d_{ij} is the distance between the transmitter i and the receiver j , η_i is the background noise energy, T_f is the pulse repetition frequency, σ^2 is an operation parameter depending on the shape of the pulse, R_i is the rate of the link i , N is the number of active links in the network, and γ_i is the threshold value of the SINR [7]. The SINR at the received side should maintain over the threshold value to achieve successful transmissions [8], [9].

In [8], UWB system characteristics, compared with narrowband wireless systems, were shown. There are no collisions in UWB Transmissions due to the use of Time Hopping Spread Spectrum (TH -SS) or Direct Sequence Spread Spectrum (DS-SS) as a multiple access techniques [10], [3] furthermore, hybrid techniques can be used [11] and hence multiple simultaneous transmissions can be occured in the UWB network. However, the near-far problem due to the strong interference from the nearby interferer nodes still exists. This problem cannot be solved by the power control at the physical layer, but should be using a jointly radio resource allocation at the data link layer. Two mechanisms were proposed to solve this problem which are spatial exclusion and temporal exclusion solutions [12]. In [8], [9], Interference Margin (IM) approach has been assumed to avoid the frequent power reconfigure for each new admitted call. Each active link has an IM value, given by (2), which donates the additional interference by any new link request.

$$IM_i = \frac{P_i g_{ij}}{R_i \gamma_i} - \eta_i - T_f \sigma^2 \sum_{k=1,k\neq i}^{N} P_k g_{kj} \quad (2)$$

The proposed MAC protocol utilizes the no collisions feature of UWB transmissions due to the use of TH-SS. Furthermore, the proposed algorithm for resource allocation will depend on IM calculation which will be explained later.

III. THE PROPOSED PROTOCOL DESCRIPTION

The proposed protocol is based on two channels (data and control channels). The data channel is used for transmission of packets from transmitting node to receiving node. While the control channel is used for link requesting or link termination. The wireless personal area network (WPAN) or the piconet consists of PNC assumed as a central node and all other terminals nodes. The PNC is responsible for timing (with the beacon) and resource allocation in the associated piconet. The transmission is based on the superframe for data and control channel in parallel as shown in Fig. 1. The data channel is partitioned into slots and the first slot is the superframe beacon which is used for synchronization as mentioned before. The control channel is also divided into the same number of slots furthermore, each slot is subdivided into uplink (from the terminal to PNC) and downlink (from PNC to the terminal) subslots.

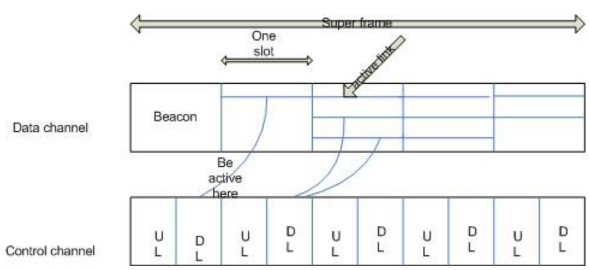

Fig. 1. Data and control channels in the piconet superframe.

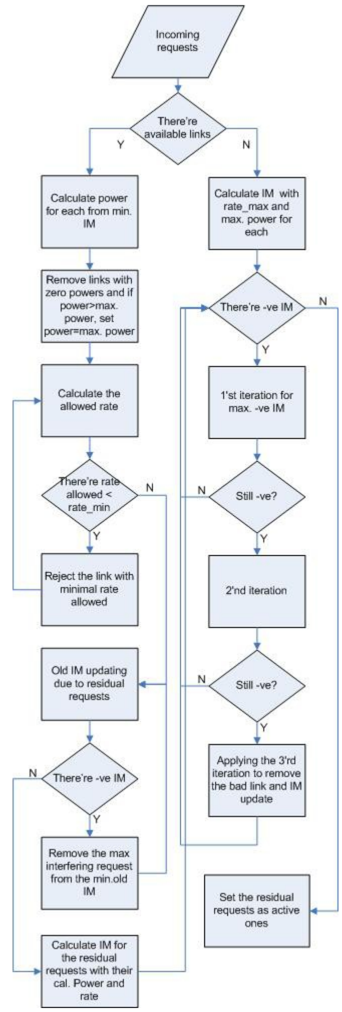

Fig. 2. Flowchart of WALAC.

For proposed protocol, the steps can be summarized as follows;

1) If a terminal has traffic to send, it sends a request to the PNC including the transmitter identification (ID) and the receiver ID through the uplink subslot in the control channel. Each node will send with a certain code, therefore there are no collisions here.
2) The PNC collects all requests and applies the proposed WALAC which will be described below. Over there, the PNC sends information to requesting terminals through the downlink subslot using a common code to indicate the situation of each terminal, i.e., admitted or rejected.
3) The admitted links will send the data traffic in the next slot in the data channel while the rejected ones try agian in the next slot.
4) When a terminal needs to terminate its link, it informs the PNC through the control channel.

Fig. 2 shows the flowchart of the proposed WALAC. In this algorithm, the PNC seeks if there are available links in the system. If there are no links in the system, it calculates IM for all incoming requests from (2) using the maximum power (P_{max}) according to the optimum power control described in [13] and the maximum rate (R_{max}) to achieve the minimum delay. Then searching for the negative (-ve) IM from the calculated matrix, if any, the minimum one will be selected to achieve fairness and reduce its rate to the median value. Then its IM again will be calculated from (2). If it is still -ve then the second iteration will be applied to reduce the rate to the minimum value (R_{min}) and repeated. After that if IM still -ve, remove it from the requests. Then update all links and repeat again. If the IM becomes positive (+ve) or zero, search for another -ve IM and do the same process. If not, set the residual requests as admitted links. In the opposite vein, if there are available links in the system. The PNC calculates the allowed power for each request from the minimal IM of active links from (3). Then remove the power with zero value and let $P_0 = P_{max}$ (if $P_0 > P_{max}$). Calculate the allowed rate in the system for each request from (4). If there are rates lower than R_{min}, reject the request with minimal allowed rate (to achieve fairness) then repeat again till all allowed rates be greater than R_{min}. Update all active links in the network to see if they will be disturbed by the new requests or not. If any one be -ve IM, remove the maximum interfering request from the minimal IM to achieve fairness. Then update the IM again and repeat till no -ve IM in the links. Calculate the IM for the residual requests with their calculated power and rate which will be considered as the maximum rate for that request and then apply the same procedure as if there are no links available in the network. From pervious procedures, fairness between the contended requests is achieved by WALAC.

$$P_0 = min\left(\frac{IM_i}{T_f\sigma^2 g_{0i}}\right) \quad where\ 1 \leq i \leq N \qquad (3)$$

$$R_{allow} = \frac{P_0 g_{ij0}}{\gamma\left(\eta_i + T_f\sigma^2 \sum_{k=1,k\neq i}^{N} P_k g_{kj0}\right)} \qquad (4)$$

IV. Simulation Results and Discussions

In this section, we study the behavior of the centralized protocols through simulations. The simulation area is taken as 50m×50m with nodes randomly distributed. The data traffic flows are generated based on a Poisson process with λ call/sec per user. The default parameters used are shown in TABLE I.

TABLE I
Simulation Parameters

Parameter	Value
T_f	10 ns
σ^2	1.99×10^{-3}
η	2.56×10^{-17}
P_{max}	7 dBm
λ	30
α	4
γ	6 dB
superframe duration	20 msec
no. of slots in superframe (including Beacon)	5
packet length	1024 bytes
permission	0.3
buffer rate	10 Mb/s
minimum rate (R_{min})	2 Mb/s
maximum rate (R_{max})	100 Mb/s

Comparison between Slotted Aloha, PRMA, and the proposed protocol in a high rate UWB network is done. Slotted Aloha system is based on the channel organized into uniform slots whose size equals to the packet transmission time. If a station needs to send a packet, it sends in the first next slot. Aloha based channel access was proposed in [14], but there was the contention problem. PRMA system is similar to Slotted Aloha system except that the users can reserve the slots till finishing their transmissions if they success for contention it. To access the channel, it must first have permission over the threshold value [15]. The protocols are compared, for both data traffic and streaming data traffic, according to the following parameters which are considered a measure of the system performance and the protocol effectiveness.

- **System throughput**: the ratio between the successfully transmitted packets and all transmitted packets.
- **System utilization**: the ratio between the successfully transmitted bits averaged over the time.
- **System loss probability**: the ratio between the rejected transmitted packets and all transmitted packets.
- **System average delay**: the average delay per successfully packets.
- **Admission ratio**: admission ratio parameter is defined as the ratio between the admitted requests and the all incoming requests. It is a parameter for the proposed protocol.

Fig. 3 and 4 show the system normalized throughput for the data and streaming data traffic respectively. The two curves indicate that the proposed protocol is better than both Slotted Aloha and PRMA systems in both types of traffic. In low traffic or low number of data terminals, Slotted Aloha has better throughput than PRMA. That is because the reserved slots in PRMA decreases the available number of channels for the contented users. While in high traffic or great number of data terminals, PRMA and Slotted Aloha nearly shows the same performance. That is because the collisions for both protocols are assumed to be equal and the reserved channels in PRMA loses their advantage. On the other hand, the proposed protocol shows better throughput than others in both low and high traffic as there are no collisions. For data traffic, Slotted Aloha system can serve 24 data users while PRMA works up to 20 users. The proposed protocol can attend more than 60 data users. For streaming data traffic, number of users is retrograded to only five users for Slotted Aloha and to 10 users for PRMA while they are still above 60 ones for the proposed protocol but with lower throughput. The PRMA enhancement over Slotted Aloha is because the reserved channels in PRMA serve some streaming nature users where this is not found in Slotted Aloha which suffers with a lot of collisions.

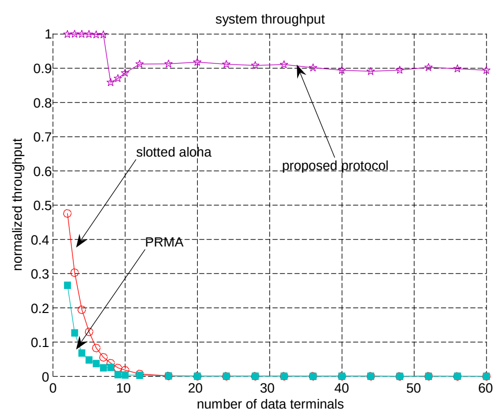

Fig. 3. System throughput for data traffic

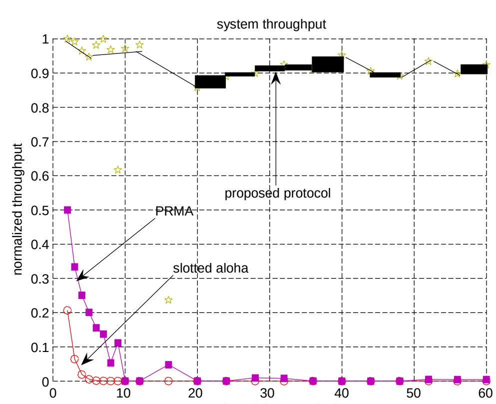

Fig. 4. System throughput for streaming data

The utilization for the three systems is compared for both data and streaming data traffic in Fig. 5 and 6 respectively. The proposed protocol shows better channel utilization than others. From the curves, Slotted Aloha is 16% better than PRMA in low traffic while PRMA is better by 50% in streaming data. For the proposed protocol, it gives better performance than Slotted Aloha more than 60% in low traffic and better than PRMA in streaming data more than 83%. This better performance comes from the use of WALAC which allows the user to share the channel with others without degradation.

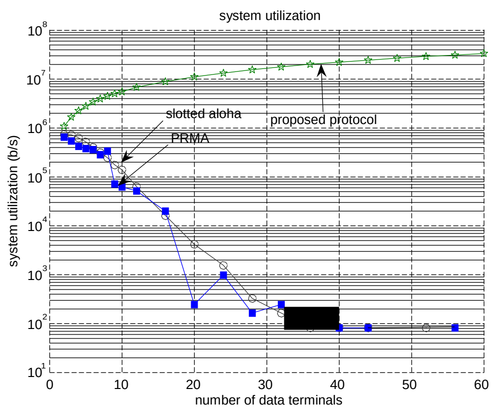

Fig. 5. The system utilization of the three protocols

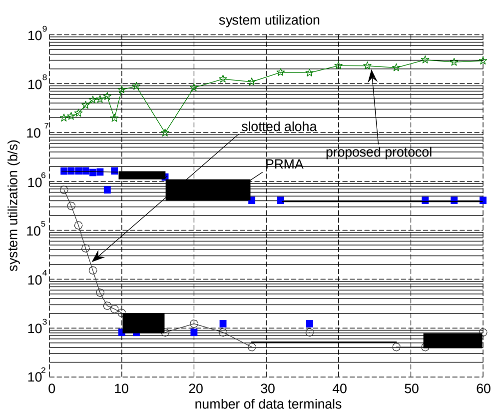

Fig. 6. System utilization under streaming data.

Fig. 7 shows the loss probability of the compared protocols for data traffic while Fig. 8 shows it for the streaming data traffic. The proposed protocol has the lowest loss probability compared with the other systems. That is because of the use of TH codes for each user and hence no collisions as in the other systems. The loss packets in the proposed system come from only the rejected requests. Furthermore, the loss probability in streaming data is more than data traffic and nearly will be saturated in the proposed protocol at a value lower than the other systems due to the high load of the system.

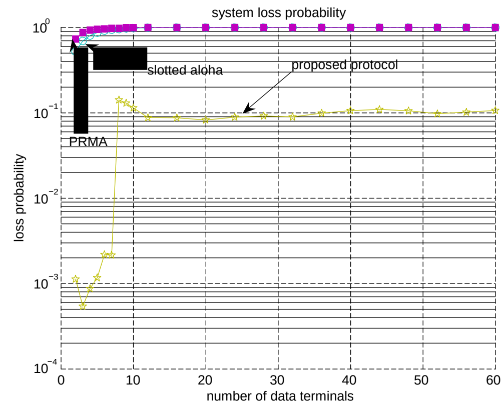

Fig. 7. System loss probability.

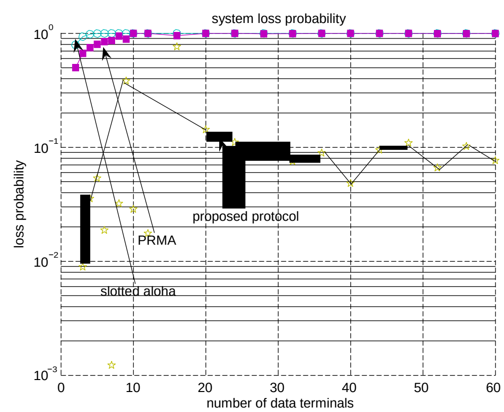

Fig. 8. System loss probability under streaming data

The average delay for PRMA is larger than Slotted Aloha system and both of them give higher average delay compared with the proposed protocol for data traffic as shown from Fig. 9. That is because the presence of the reserved channels in PRMA which increases collisions for the additional users. For streaming data as shown from 10, The average delay for Slotted Aloha is larger than PRMA system and both of them are still higher than the proposed protocol. That is because the collision increment due to the streaming nature of the data and the absence of the advantage of the reserved channels to serve portion of low traffic streaming data users as in PRMA. Fig. 11 and 12 show the proposed protocol average delay in both types of data to indicate that the average delay increases with the increase of the number of the users and hence saturates.

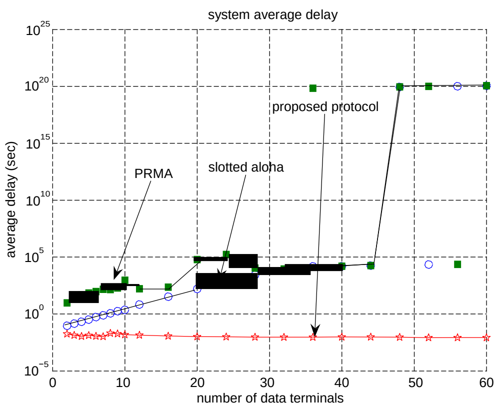

Fig. 9. System average delay

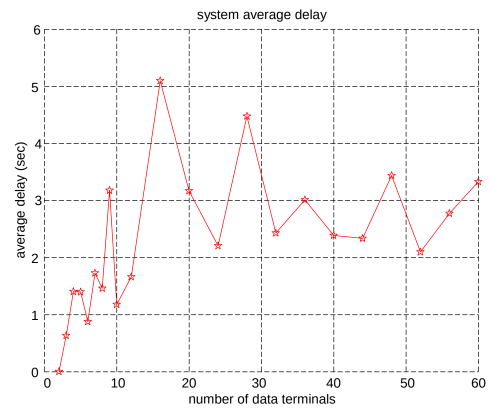

Fig. 12. The proposed protocol average delay for streaming data

The admission ratio of the proposed system is decreased with the increase of the number of data terminals. For more users, the active links will increase and the probability of the admission of new user will decrease. Whenever more links available, interference will increase. The interference margins will decrease and hence low probability of admission of new requests. Fig. 13 depicts the admission ratio for both types of data versus the number of link terminals. For streaming data traffic, low admission ratio can be noticed.

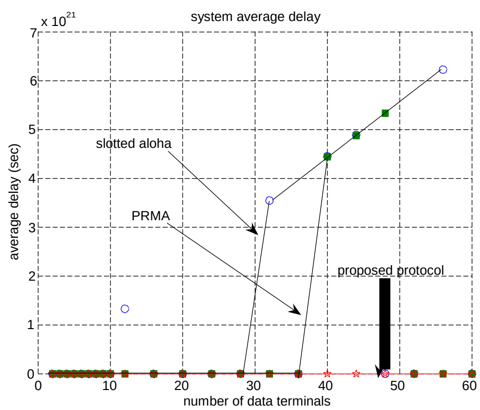

Fig. 10. System average delay for streaming data

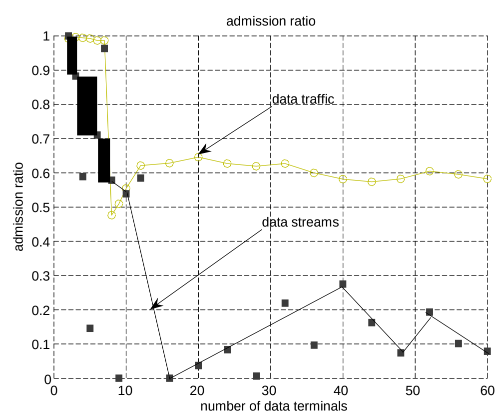

Fig. 13. Admission ratio

V. CONCLUSION

In this paper, a new protocol was proposed. By using this proposed protocol, the network performance will be enhanced due to the increment of capacity. Comparisons between the proposed protocol, Slotted Aloha and PRMA were made. From these comparisons, we conclude that the proposed protocol gives better performance in both data traffic and streaming data of system throughput, channel utilization, average delay, and loss probability than others.

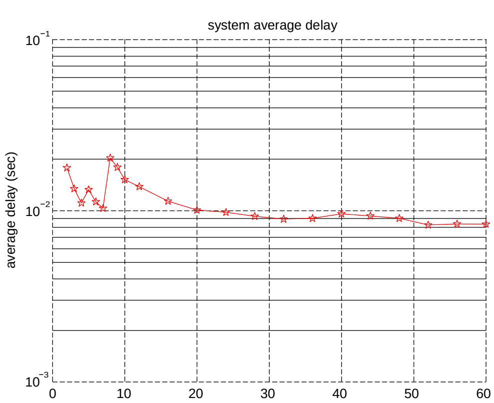

Fig. 11. The proposed protocol average delay

REFERENCES

[1] *First report and order in the matter of revision of part 15 of the commission's rules regarding ultra-wideband transmission systems*. Fedral Communications Commission (FCC 02-48), Apr. 2002.

[2] X. S. Shen, H. Jiang, and J. Cai, "Medium access control in ultra-wideband wireless networks," *IEEE TRANSACTIONS ON VEHICULAR TECHNOLOGY*, vol. 54, pp. 1663–1677, 2005.

[3] *DS-UWB Physical Layer Submission to 802.15 Task Group 3a*. IEEE P802.15-04/0137r5, September 2005.

[4] *MultiBand OFDM Physical Layer Proposal for IEEE 802.15 Task Group 3a*. MultiBand OFDM Alliance SIG, 2004.

[5] *Part 15.3: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for High Rate Wireless Personal Area Networks (WPANs)*. IEEE Computer Society, 29 September 2003.

[6] *Part 15.3: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for High Rate Wireless Personal Area Networks (WPANs) Amendment 1: MAC Sublayer*. IEEE Computer Society, 5 May 2006.

[7] M. win and R. Scholdtz, "Ultra-wide bandwidth time-hopping spread-spectrum impulse radio for wireless multiple-access communications," *IEEE Transactions on communication*, vol. 48, pp. 649–691, April 2000.

[8] Y. Chu and A. Ganz,"Mac protocols for multimedia support in uwb-based wireless networks." Available at: www.broadnets.org/2004/workshop-papers/Broadwim/broadwim2004-Paper09-yuechun.pdf.

[9] F. Cuomo, C. Martello, and A. Baiocchi, "Radio resource sharing for ad hoc networking with uwb," *IEEE JOURNAL ON SELECTED AREAS IN COMMUNICATIONS*, vol. 20, NO. 9, pp. 1722–1732, Dec. 2002.

[10] H. Yomo, P. Popovski, C. Wijting, I. Z. Kovacs, N. Deblauwe, A. F. Baena, and R. Prasad, "Medium access techniques in ultra wideband ad hoc networks." This paper describes work undertaken partly in the context of the IST-2001-34157 Power aware Communications for Wireless OptiMised personal Area Network (PAC-WOMAN). The IST program is partially funded by the EC. Available at: http://cpk.auc.dk/FACE/documents/Publication/hiro/etai.pdf.

[11] M. Mezzour, "Direct spread spectrum (ds) / time hopping (th) uwb performances comparison in a multi-user ad hoc environment." Available at: www.mics.ch/SumIntU04/MohamedMezzour.pdf.

[12] H. Jaing, W. Zhuang, and X. S. Shen, "Effective interference control in ultra-wideband wireless networks," *IEEE VEHICULAR TECHNOLOGY MAGAZINE*, pp. 39–46, SEPTEMBER 2006.

[13] B. Radunovic and Jean-Yves, "When power adaptation is useless or harmful," tech. rep., IC, 2004/60.

[14] F. Legrand, I. Bucaille, S. Héthuin, L. D. Nardis, G. Giancola, M. D. Benedetto, L. Blazevic, and P. Rouzet, "Ultra wide band system: Mac and routing protocols," *International Workshop on Ultra Wideband Syatems, IWUWBS, Oulu, Finland*, April 25, 2003.

[15] D. J. Goodman and S. X. Wei, "Efficiency of packet reservation multiple access," *IEEE TRANSACTIONS ON VEHICULAR TECHNOLOGY*, vol. 40, no. 1, pp. 170–176, Feb. 1991.