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Enhanced Distributed Exclusive Region Based MAC Protocol for UWB Channels with Fast Fading and Shadowing

[1]Y.V. Adi Satyanarayana, [2]K. Padma Raju and [3]P.V. Naganjaneyulu
[1]Department of E.C.E, Jawharlal Nehru Technologycal University Kakinada, JNTUK, Andhra Pradesh, India
[2]Director of Academics and Planning, Jawharlal Nehru Technologycal University Kakinada, JNTUK, Andhra Pradesh, India
[3]M V R College of Engineering and Technology, Paritala, Andhra Pradesh, India

Abstract: In the presence of UWB channels that provide large bandwidth and potential possibilities for high quality services and applications in wireless networks MAC protocol plays a vital role in utilizing the channels effectively. Recently, Cai explored the notion of exclusive region for building Distributed Exclusive Region (DEX) based MAC protocol. DEX MAC improved performance of wireless network for using UWB channels effectively in distributed and asynchronous fashion. However, their protocol was not evaluated in the presence of fast fading and shadowing conditions of UWB channels. In this study, we design EDEX (Enhanced DEX) based MAC which has contingency measures in the presence of such conditions. The EDEX thus works for dense network with high data rate requirements. We implemented EDEXMAC using NS2. The simulation results are compared with other existing DEX based MAC protocols.

Key word: UWB channels, exclusive region, MAC protocol, fast fading, shadowing

INTRODUCTION

MAC is a protocol which lies as the data link layer in wireless communication networks. With respect to broadband wireless communications Ultra-wideband communication is the crucial technology. It can achieve data rate up to Gbps. Thus, it is widely used in data intensive applications. However, the synchronization and scheduling in such networks is considered costly and difficult. Therefore, it is essential to implement a robust MAC protocol that can help in optimization of the functionalities pertaining to data link layer in wireless networks. As the network is expected to have data intensive application, the problems like unfairness and throughput starvation are concerns in such networks. To overcome these issues, many researchers contributed. One recent contribution is from Cai *et al*. (2009) where a MAC protocol is designed and optimized for exploring exclusive region in UWB channels in order to have fair and efficient sharing of resources. This could improve the performance of network so as to improve the communications between two parties through the exclusive region. In other words scheduling and synchronizations were achieved.

The MAC protocol designed by Cai *et al*. (2009) is improved further in EEDRP (Satyanarayana *et al*., 2015), RAMM (Satyanarayana *et al*., 2016 a,b) and DEXRSSMAC (Satyanarayana *et al*., 2015). Adisatyanarayana *et al*. (2014) also there is research on the improvement of Cai *et al*. (2009) work with respect to finding exclusive region using directional antenna. More details can be found in where review of relevant literature is made.

In this study we proposed a protocol for enhancing synchronization and scheduling in UWB channels in data intensive broadband networks. Our protocol is named as Distributed Exclusive Region (DEX) based MAC (EDEXMAC) protocol. This protocol is optimized for finding exclusive region in UWB channels even in the presence of fast fading and shadowing conditions. More details on fast fading and are provided. With optimization the proposed protocol is aware of the two conditions of UWB channels with required contingency plans. Thus, the protocol achieves improved performance over its predecessors.

The protocol performs better in the fast fading and shadowing conditions of UWB channels and ensures fair and efficient sharing of resources to facilitate enhanced

Corresponding Author: Y.V. Adi Satyanarayana, Department of E.C.E , Jawaharlal Nehru Technological University Kakinada, JNTUK, Andhra Pradesh, India

performance. The protocol is evaluated with NS2 simulations. It is compared with other existing protocols such as DLBOP, EEDRP and DEXRSSMAC. The empirical results revealed that the EDEXMAC outperforms other protocols.

Literature review: Shen *et al*. (2005) explored UWB channels and medium access control which has impact on quality of services. They explored MAC improvement with UWB channels in order to enhance the sharing of resources for higher bit rate. Cardinali *et al*. (2006) analyzed UWB ranging accuracy in different applications with high low data rate. The best ranging accuracy is achieved when OFDM with MB. Pagani focused on ultra-wideband radio propagation channels with large frequency bandwidths. They found that UWB channels are promising future networks for high bit rate data transmission. Cully *et al*. (2012) investigated Line of Sight (LOS) and Non Line of Sight (NLOS) for models in order to mitigate the effect of body shadowing. They studied the effects of blocking by human body in wireless field. They used RSS based monte carlo localization technique for achieving this.

Chung (2012) made experiments on the suppression of Multi-user Access Interference (MAI) in order to find the effects in UWB system. They explored an adaptive Least Bit Error Rate (LBER) receiver CDMA system for synchronous communication. Their method was proved to be effective in suppressing MAI. Stephan *et al*. (2008) focused on the study of combining CDMA and OFDM for achieving high data bit rate in UWB networks. Schilcher *et al*. (2012) explored a kind of fading known as Reyleigh block fading. They derived closed form expressions from this and slotted ALOHA traffic for modelling interference power and investigated temporal correlation of interference.

Abbasi *et al*. (2012) proposed a method for radio channel characterization with antenna diversity techniques of UWB. They found that diversity is the tool that can be used for combating fading. Saadane and Wahbi (2012) used ray tracing technique in the presence of shadowing due to human body with respect to indoor radio propagation modelling of UWB. Guo *et al*. (2012) proposed a scheme related to joint network-channel coding to achieve reliable communication in wireless networks. They used non binary version of the scheme for exploiting spatial diversity redundancy.

Landolsi studied on the line of sight and channel estimation in UWB networks. Their work is based on Unscented Kalman Filter (UKF) and exploration of channel response conditions. Their classification of conditions into LOS and NLOS were highly accurate. Abbasi (2012) focused on Body Centric Wireless Network (BCWN) with UWB to have next generation wireless network. Especially they characterized and modelled radio channel characterization of such networks. Makki *et al*. (2012) investigate on fast fading channels based on Automatic Repeat request (ARQ). Their investigation includes both slow fading and fast fading channels with ARQ protocols. They found higher performance with fast fading channels.

Radunovic and Boudec (2004) studied routing in UWB networks to know how they perform in terms of scheduling and optimal power control. They took it as a mathematical optimization problem and used simple networks to demonstrate the effectiveness of UWB channels. Xiao *et al*. (2012) studied multi-user and multi-relay networks for the design of network codes for asymmetric performance. The coding approach they followed is named as Maximum Distance Separable (MDS).

Reig and Rubio (2013) and Quevedo *et al*. (2013) focused on estimation of fast fading and shadowing besides their distribution dynamics in wireless networks. They characterized the concept of fast fading and shadowing. Abbasi *et al*. (2013) explored antenna diversity techniques for radio propagation modelling of UWB. Various shadowing approaches and the diversity techniques were investigated. Their investigations revealed that the results were having only error rate 0.8 dB. Thus their study proves significance of diversity techniques.

Quevedo *et al*. (2013) explored the process of state estimation in sensor networks in the presence of fading channels. They used the notion of network state process which is a set of finite states and transitions to analyze stability conditions. Mukherjee *et al*. (2014) focused on physical layer security in wireless networks where multiple users access the network. Sun *et al*. (2016) investigated on the insights of cooperative wideband spectrum sensing in the presence of fading channels. They found that wide band network can be sensed so as to understand channel conditions and make use of them to increase bit rate. Mukherjee and Nath (2015) discussed issues and challenges in cognitive radio networks with respect to spectrum management. They found that cognitive radio technology was powerful and adaptable for optimal usage of spectrum.

Preliminaries

Fast fading and shadowing: Variation in signal strength is called fading. Fast fading exhibits quick variations in signal strength while slow fading does not exhibit that quickness in variation as it is generally due to mobility. Shadowing due to obstructions in line of sight, causes slow fading. With respect to UWB channels, UWB signals propagate via air. The attenuation of signal strength can happened for three reasons. First reason is the spreading of energy of the radio wave over increasing area. This is also known as path loss. Second reason is obstacles that can block radio waves. It is known as shadowing or fading in large scale. Third reason is multipath propagation which causes fading in small scale. An UWB wave can encounters different situations known as long-term path loss, medium-term path loss or slow fading and short term path loss or fast fading.

Long-term path loss: Here the path loss is gradual as the received power decreases with logarithmic scale showing exponential decay.

Medium-term path loss: Here, the pass loss is due to obstructions such as buildings. It exhibits random fluctuations and random variations cause total path loss. It results in large scale fading which is also known as shadowing.

Short-term path loss: It shows sudden variations in signal strength because of multi-path propagation due to moving objects. Here multipath components exhibit overlapping and summed up. Destructive adding of such components is the reason for fading.

These three effects are found in the real time in different proportions. The propagation phenomena can be represented in terms of channel impulse response h (t) between received and source signals y (t) and x (t) respectively. Multiple paths are used to represent channel. They contain propagation delays $\{\tau_i\}$ and real positive gain {Ei where path index is represented as i. The following is used to compute channel impulse response:

$$h(t) = \sum_{i=1}^{N} E_i(t)\,\delta(t - \tau_i(t))$$

Here, dirac delta function is used which is represented as δ (·). Sun of N scattered Ei (t) is used to describe channel impulse response where N value is between 6 and 20. Each scattered Ei is nothing but the sum of N waves. The summation is thus able to represent short term characteristic. In the context of fast fading effects, it is essential to remember about medium and long term variation in attenuation of each scatter:

$$E_i(t) = At_i(t) \cdot E_{iFF}(t)$$

Simple analysis is often limited to long-term average which varies with distance and even with an exponential law. The total loss is computed as follows:

$$PL(d) = PL_o + 10n\log_{10}\left(\frac{d}{d_0}\right)$$

The geometric centre frequency of UWB waveform is represented by f_c. Waveform spectrum's dB edges are represented as f_{min} and f_{max}. Path loss component is denoted as n.

Code-Division Multiple Access (CDMA): It refers to protocols used in 2G or 3G wireless communications. It is a form of multiplexing which supports various signals to share same channel thus optimizing utilization of bandwidth. CDMA is equipped with Analog to Digital Conversion (ADC) besides spread spectrum technology. Various patterns or codes are used in order to see variation in transmitted signals. UWB channels when combined with CDMA technology can increase performance as explored in Stephan *et al.* (2008). Especially CDMA contributes to high bit rates in UWB channels. Therefore it is considered in the research of this study:

$$PL_0 = 20\log\left(\frac{4\pi f_c d_0}{c}\right)$$

where, PL_0 represents the intercept point which represents path loss at distance d_0 and the intercept point is computed as follows:

$$f_c = \sqrt{f_{min} f_{max}}$$

METERIALS AND METHODS

Resarchers proposed a new protocol in this study. It is named EDEXMAC (Enhanced Distributed Exclusive Region Based MAC). It is an extension to the original Distributed Exclusive Region (DEX) MAC protocol which optimizes communications in UWB channels. Since UWB channels provide higher bandwidth and suitable for data intensive applications, finding exclusive region for supporting fair and efficient sharing of resources can further optimize performance of such networks. For this reason in our previous study we proposed Distributed Exclusive Region Based MAC Protocol (DEXRSSMAC). In this study we focused on understanding two conditions in UWB channels namely fast fading and shadowing. These two contingencies are addressed by optimizing the proposed protocol named EDEXMAC. The improvements in MAC could help finding exclusive region for efficient communication besides handling fast fading and shadowing conditions. As shown in Fig. 1, it is evident that the proposed protocol enhances the DEX protocol proposed in Lin and colleagues by proposing optimization by analyzing fast fading and shadowing

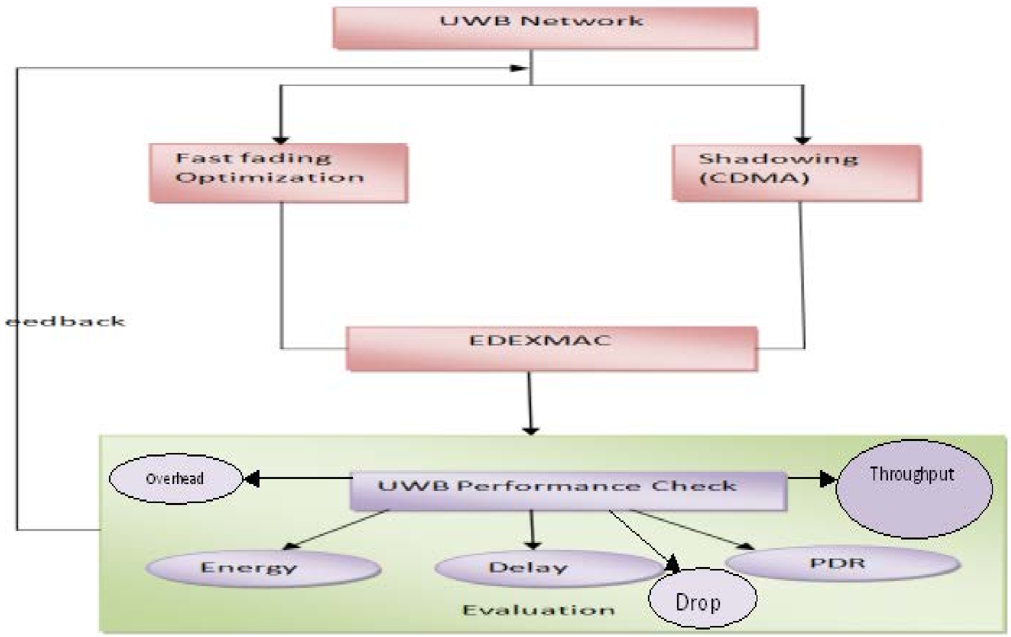

Fig. 1: Overview of the proposed architecture

conditions in UWB channels. The proposed EDEXMAC protocol is aware of the fast fading and shadowing conditions. The two channel conditions are described with analysis. This know how is the basis for our optimization mechanism. After adapting to the channel fast fading and shadowing conditions, the protocol is aware of such conditions and the optimization comes into picture. Thus the proposed protocol starts working with considerable performance improvement (Fig. 1).

RESULTS AND DISCUSSION

Resarchers implemented the proposed EDEXMAC (Enhanced Distributed Exclusive Region Based MAC) protocol using NS2 simulations. The protocol supports exclusive region based optimization of communication to provide fair and efficient sharing of resources of UWB channels in the presence of fast fading and shadowing conditions. The environment used for the empirical study is shown in Table 1 shows performance metrics used to evaluate the results of our work.

As shown in Table 1, the environment used for empirical study through NS2 simulations is presented. Performance Metrics.The performance metrics presented in Table 2 are used to evaluate our work. The results are observed in terms of these measures.

Packet delivery ration is presented in Table 3. The results are observed at different simulation times. The results of our protocol named EDEXMAC are compared with existing protocols such as DLBOP, EEDRP and as simulation time increased. When compared with other protocols, EDEXMAC showed higher packet delivery ratio. The rationale behind this is that it exploits exclusive region in UWB channels for fair and efficient sharing of resources in the presence of fast fading and shadowing.

Table 1: Simulation environment

Parameter type	Parameter value
Channel type	Channel/wireless channel
Radio-propagation model	Propagation/shadowing
Antenna type	Antenna/omni antenna
Link layer type	LL
Interface queue type	Drop tail
Network interface type	Phy/wireless phy
MAC type	Mac/802_11
Routing protocol	EDEXMAC
Number of mobile nodes	11
Network area	600 x 600
Interface queue size	50
Shadow model range	150

Table 2: Performance metrics

Metric	Description
Packet Delivery Ratio (PDR)	It is the performance measure used to know the ratio between number of packets received and the number of packets sent
Throughput	The rate of messages transferred successfully in network
Average delay	The time difference between packets received and packet sent
Energy consumption	It is the measure used to know how much energy is consumed by the network in data
transmission, sensing	data processing and idle sleep state
Packet drop	It is the number of packets dropped by the
protocol for any reason	
Communication overhead	It is the cost of communication while the proposed scheme is operating

Table 3: PDR performance comparison

Simulation time (sec)	10	15	20	25
DLBOP	0.18	0.20	0.12	0.12
EEDRP	0.25	0.20	0.27	0.27
DEXRSSMAC	0.30	0.28	0.37	0.39
EDEXMAC	0.35	0.30	0.39	0.42

Table 4: Packet drop comparison

Simulation time (sec)	10	15	20	25
DLBOP	2000	3800	5800	8000
EEDRP	500	1500	2000	2000
DEXRSSMAC	300	1300	1700	1800
EDEXMAC	100	1000	1500	1600

Table 5: Energy consumption

Simulation time (sec)	10	15	20	25
DLBOP	8	11	12	14
EEDRP	8	10	11	11
DEXRSSMAC	10	12	14	16
EDEXMAC	12	14	16	18

The packet delivery ratio as shown in Fig. 2 is more with EDEXMAC which is the protocol proposed and implemented in this study. Its performance is better than all other protocols. DEXRSSMAC performs better than DEXRSSMAC. The results revealed that PDR is increased EEDRP and DLBOP. EEDRP is better than DLBOP in terms of packet delivery ratio. The trend in the results observed is that PDR increases as simulation time increases.

Packet drop is observed in the simulations and presented in Table 4. The results revealed that the packet drop is more as simulation time increases.Another observation is that EDEXMAC shows less packet drop issue when compared with all other protocols. After this, DEXRSSMAC shows better performance when compared with DLBOP and EEDRP.

Packet drop, as shown in Fig. 3, is least when proposed protocol EDEXMAC is used. Its performance is comparable with other protocols such as DEXRSSMAC, EEDRP and DLBOP. The other protocols show increase in packet drop. DLBOP exhibits highest packet drop behaviour. Therefore, the proposed protocol is performing better in terms of packet drop.

Energy efficiency, as shown in Table 5, of different protocols is presented. The proposed protocol EDEXMAC shows highest performance. It consumes less energy source when compared with other protocols such as DEXRSSMAC, EEDRP and DLBOP. As the simulation time increases the residual energy is reduced. However, the proposed protocol outperforms other protocols.

As shown in Fig. 4, it is evident that the EDEXMAC shows highest performance. The least performance is exhibited by DLBOP. The other protocols such as EEDRP and DEXRSSMAC show more energy consumption when compared with EDEXMAC. The energy is measured in joules and presented in vertical axis while the simulation time in seconds is presented in horizontal axis. As shown in Table 6, it is evident that the proposed protocol is able

Table 6: Communication overhead comparison

Simulation time (sec)	10	15	20	25
DLBOP	1200	1500	2200	2800
EEDRP	200	500	800	800
DEXRSSMAC	100	400	600	700
EDEXMAC	50	300	500	600

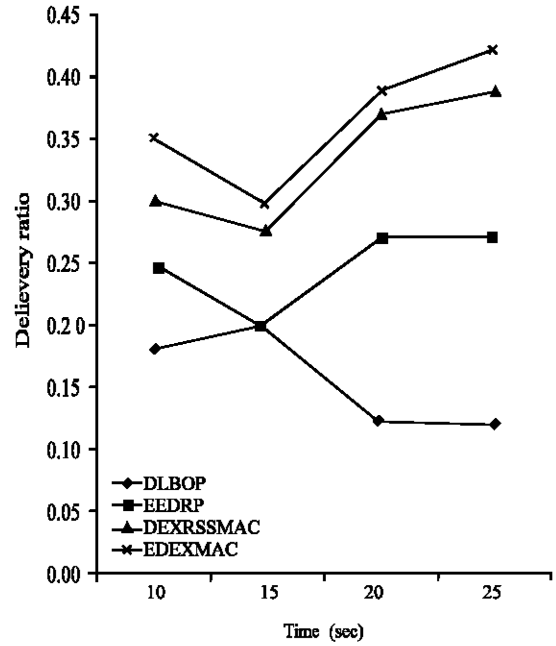

Fig. 2: PDR performance comparison

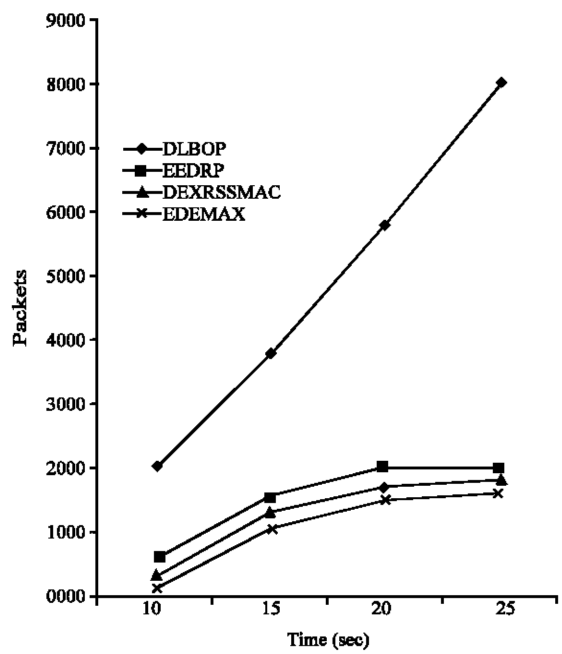

Fig. 3: Packet dropping comparison

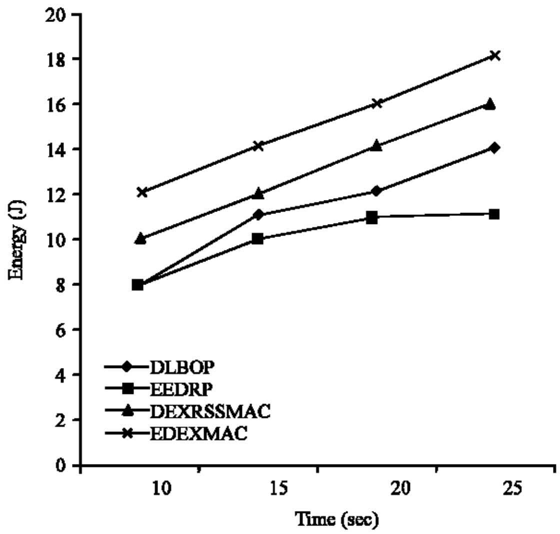

Fig. 4: Energy efficiency comparison

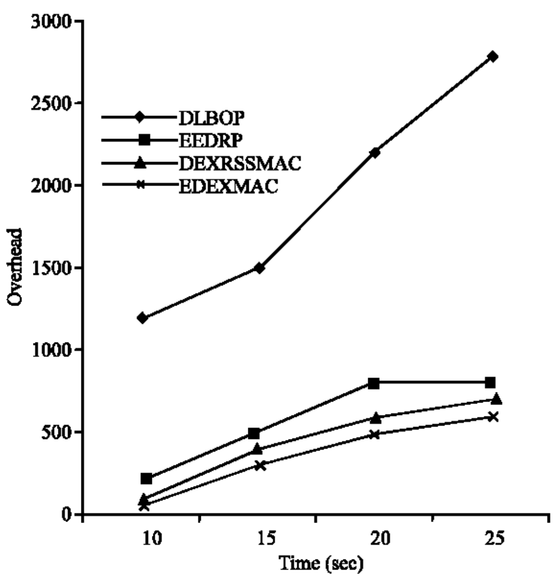

Fig. 5: Overhead comparison

to reduce communication overhead significantly as there is exclusive region that can get optimized in the presence of fast fading and shadowing with respect to UWB channels. The EDEXMAC protocol outperforms other protocols with respect to communication overhead. The least performance is shown by DLBOP while the DEXRSSMAC shows superior performance when compared with its predecessors such as EEDRP and DLBOP.

As shown in Fig. 5, the communication overhead of different protocols is presented. The results reveal that the proposed scheme named EDEXMAC shows better performance when other protocols. As shown in Table 7, it is evident that the delay performance of DEXRSSMAC

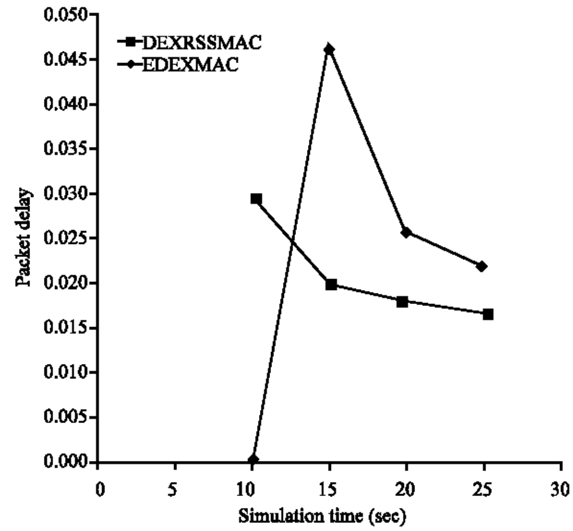

Fig. 6: Delay performance comparison

Table 7: Delay performance comparison

Simulation time (sec)	Delay performance DEXRSSMAC	EDEXMAC
15	0.047	0.020
20	0.026	0.018
25	0.022	0.017

Table 8: Throughput performance comparison

Simulation time (sec)	Throughput performance DEXRSSMAC	EDEXMAC
10	0.000	55328
15	42560	52560
20	42560	54048
25	42560	52560

is compared with the proposed protocol. The proposed protocol shows less delay as it is optimized with exclusive region in the presence of fast fading and shadowing in UWB channels.

As shown in Fig. 6, it is evident that the proposed protocol shows reduction in delay as simulation time increases. Its performance is better than that of DEXRSSMAC which is not optimized in the presence of fast fading and shadowing with respect to UWB channels.

The throughput performance, as shown in Table 8, is observed. The results revealed that the performance of EDEXMAC is significantly better than its counterpart that is not optimized for fast fading and shadowing conditions in UWB channels. For the same reason the proposed protocol shows better performance over DEXRSSMAC. As shown in Fig. 7, the number of bytes of data transmitted is presented in vertical axis while the horizontal axis shows simulation time in seconds. The results revealed that the throughput of the proposed protocol is significantly better than that of the existing one named DEXRSSMAC.

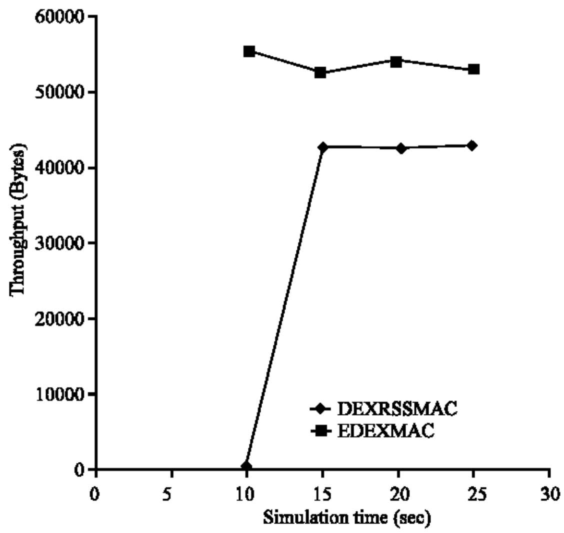

Fig. 7: Throughput performance comparison

CONCLUSION

In this study we studied UWB channels for finding exclusive region for improving performance with fair and efficient communication between two parties in the presence of conditions such as fast fading and shadowing. Researchers enhanced the recent protocol named Distributed Exclusive region (DEX) based MAC protocol proposed by Cai *et al*. (2009). The protocol is named as Enhanced Distributed Exclusive Region Based MAC (EDEXMAC) protocol. This protocol has contingency plans for overcoming issues of fast fading and shadowing. It has got optimizations to handle UWB channel conditions such as fast fading and shadowing. We implemented the proposed EDEXMAC using NS2. Our simulation results are compared with other existing DEX based MAC protocols. The results revealed that EDEXMAC shows significant performance improvement with other protocols such as DEXRSSMAC, EEDRP and DLBOP. This research can be extended further to investigate DEX optimizations in the real world UWB channels to evaluate their efficiency.

REFERENCES

Abbasi, Q.H., 2012. Radio channel characterisation and system-level modelling for ultra wideband body-centric wireless communications. Ph.D Thesis, Queen Mary University of London, London, England.

Abbasi, Q.H., A. Alomainy and Y. Hao, 2012. Ultra wideband antenna diversity techniques for on/off-body radio channel characterisation. Proceedings of the 2012 IEEE International Workshop on Antenna Technology (IWAT), March 5-7, 2012, IEEE, London, UK., ISBN:978-1-4673-0036-0, pp: 209-212.

Abbasi, Q.H., M.M. Khan, S. Liaqat, M. Kamran and A., Alomainy *et al*., 2013. Experimental investigation of ultra wideband diversity techniques for on-body radio communications. Progress Electromagnet. Res. C., 34: 165-181.

Adisatyanarayana, Y.V., K.P. Raju and P.V. Naganjaneyulu, 2014. A Mac protocol for uwb heterogeneous mobile ad hoc networks based on er by using directional antenna. Int. J. Comput. Networking Wirel. Mob. Commun., 4: 1-16.

Cai, L.X., L. Cai, X. Shen, J.W. Mark and Q. Zhang, 2009. MAC protocol design and optimization for multi-hop ultra-wideband networks. IEEE. Trans. Wirel. Commun., 8: 4056-4065.

Cardinali, R., D.L. Nardis, D.M.G. Benedetto and P. Lombardo, 2006. UWB ranging accuracy in high-and low-data-rate applications. IEEE. Trans. Microwave Theory Tech., 54: 1865-1875.

Chung, G.C., 2012. Multi-user access interference suppression for UWB system. Proceedings of the International Conference on Computer and Information Science (ICCIS), June 12-14, 2012, IEEE, Cyberjaya, Malaysia, ISBN:978-1-4673-1937-9, pp: 670-675.

Cully, W.P., S.L. Cotton, W.G. Scanlon and J.B. McQuiston, 2012. Body shadowing mitigation using differentiated LOS-NLOS channel models for RSSI-based Monte Carlo personnel localization. Proceedings of the Conference on Wireless Communications and Networking Conference, April 1-4, 2012, IEEE, Belfast, Northern Ireland, ISBN:978-1-4673-0436-8, pp: 694-698.

Guo, Z., J. Huang, B. Wang, S. Zhou and J.H. Cui *et al*., 2012. A practical joint network-channel coding scheme for reliable communication in wireless networks. IEEE. Trans. Wirel. Commun., 11: 2084-2094.

Makki, B., A.G.I. Amat, and T. Eriksson, 2012. On ARQ-based fast-fading channels. IEEE. Commun. Lett., 16: 1921-1924.

Mukherjee, A., S.A.A. Fakoorian, J. Huang and A.L. Swindlehurst, 2014. Principles of physical layer security in multiuser wireless networks: A survey. IEEE. Commun. Surv. Tutorials, 16: 1550-1573.

Mukherjee, T. and A. Nath, 2015. Issues and challenges in spectrum management in cognitive radio networks. Current Trends Technol. Sci., 4: 545-554.

Quevedo, D.E., A. Ahlen and K.H. Johansson, 2013. State estimation over sensor networks with correlated wireless fading channels. IEEE. Trans. Autom. Control, 58: 581-593.

Radunovic, B. and L.J.Y. Boudec, 2004. Optimal power control, scheduling and routing in UWB networks. IEEE. J. Sel. Areas Commun., 22: 1252-1270.

Reig, J. and L. Rubio, 2013. Estimation of the composite fast fading and shadowing distribution using the log-moments in wireless communications. IEEE. Trans. Wirel. Commun., 12: 3672-3681.

Saadane, R. and M. Wahbi, 2012. UWB indoor radio propagation modelling in presence of human body shadowing using ray tracing technique. Int. J. Commun. Networks Inf. Secur., 4: 132-143.

Satyanarayana, Y.V.A., K.P. Raju and P.V. Naganjaneyulu, 2015. Energy efficient directional routing protocol for UWB MANET. Int. J. Comput. Networks Secur., 25: 1-8.

Satyanarayana, Y.V.A., K.P. Raju and P.V. Naganjaneyulu, 2016 a. Resource allocation for multi-user multi-traffic class in UWB MANET. Int. J. Compu. Sci. Eng., 4: 1-6.

Satyanarayana, Y.V.A., K.P. Raju and P.V. Naganjaneyulu, 2016 b. DEXRSSMAC: Received signal strength for optimization of distributed exclusive region based MAC protocol. Commun. Indian J. Sci. Technol., 1: 1-10.

Schilcher, U., C. Bettstetter and G. Brandner, 2012. Temporal correlation of interference in wireless networks with Rayleigh block fading. IEEE. Trans. Mob. Comput., 11: 2109-2120.

Shen, X., W. Zhuang, H. Jiang and J. Cai, 2005. Medium access control in ultra-wideband wireless networks. IEEE. Trans. Veh. Technol., 54: 1663-1677.

Stephan, A., E. Gueguen, M. Crussiere, J.Y. Baudais and J.F. Helard, 2008. Optimization of linear precoded OFDM for high-data-rate UWB systems. EURASIP. J. Wirel. Commun. Networking, 2008: 1-10.

Sun, H., A. Nallanathan, S. Cui and C.X. Wang, 2016. Cooperative wideband spectrum sensing over fading channels. IEEE. Trans. Veh. Technol., 65: 1382-1394.

Xiao, M., J. Kliewer and M. Skoglund, 2012. Design of network codes for multiple-user multiple-relay wireless networks. IEEE. Trans. Commun., 60: 3755-3766.