Performance Analysis of Co-existence between IEEE 802.11 (Wi-Fi) and IEEE 802.16 (WiMAX) Standards without Interworking

R. H. Adekar and A. K. Kureshi

***Abstract*—After the advent of cellular standards for mobile wireless voice telephony and data transfer, IEEE 802.11 and IEEE 802.16 standards evolved for wireless broadband data transfer. The IEEE 802.11 replaced the wired LAN and IEEE 802.16 was to wireless point-to-point provide broadband data transfer. IEEE 802.11 operates in 2.4 GHz and 5 GHz band whereas IEEE 802.11 which was initially designed to operate on licensed band, later switched to 2-11 GHz band. However, both these standards used 5 GHz unlicensed band for transmission causing the possible overlap of channels. The designed protocols fairly allow the sharing on ad-hoc basis. IEEE 802.11 operated in distributed coordination mode using Distributed Coordination Function (DCF) and point coordinated mode using a dedicated coordinator node called as Point Coordination Function (PCF). However, DCF mode allows spectrum sharing for multiple users. Both standards were not designed for coexistence and thereby they may cause interference to each other, degrading their performance. Mechanisms can be designed at various layers such as MAC or PHY to enable the coexistence with desired QoS.**

In this paper, performance analysis of the impact of possible interference between IEEE 802.11 and IEEE 802.16 devices is presented i.e multiple homogeneous systems and also heterogeneous systems. An NS2 based simulations are used to analyze the impact of interference on performance. The simulation results indicates that the performance of both the systems degrade drastically which results in degradation spectral efficiency.

***Index Terms*—Coexistence, IEEE 802.16 (WiMAX), IEEE 802.11 (Wi-Fi), MAC, PHY, spectrum efficiency, unlicensed frequencies.**

I. Introduction

Along with cellular wireless networks, the wireless networks for broadband access such as Wi-Fi (IEEE 802.11) and WiMax (IEEE 802.16) standards have been developed and exist everywhere. IEEE 802.11 standards [1] use 2.4 GHz and 5 GHz bands, whereas IEEE802.16 [2] use 2-11 GHz band. Both of these heterogeneous technologies operate in 5 GHz band, either overlapping or sharing channels. The designed protocols fairly allow the sharing on ad-hoc basis. IEEE 802.11 operated in distributed coordination mode using Distributed Coordination Function (DCF) and point coordinated mode using a dedicated coordinator node called as Point Coordination Function (PCF). The DCF mode allows spectrum sharing by multiple nodes (heterogeneous or non-heterogeneous) in the close proximity. However, PCF is not compatible for the coexistence of non-heterogeneous nodes, hence not considered in this study [1]-[8].

Initially IEEE 802.16 system was designed to operate in licensed band, however later it started operating in unlicensed band also. Since then, researchers have examined the problem of co-existence of heterogeneous systems such as IEEE 802.11 and IEEE 802.15 [3], [4] as well as IEEE 802.11 and IEEE 802.16 [5], [6]. One way to make networks coexist at the same space and time without generating harmful interference is to use dynamic frequency selection and power control. However, for Quality of Service (QoS) guarantee, more stringent strategies have to be used. Some approaches have been investigated to enable coexistence without information transfer between the heterogeneous systems [5], [7]. However, with interworking among the two heterogeneous systems can enable sharing of spectrum by using common frame structure as shown in this paper. In this paper, we analyze the performance of IEEE 802.11 and IEEE 802.16 systems without interworking under the impact of interference and further provide the interworking mechanism for coexistence [9], [10].

In Section II the co-existence problem between IEEE 802.11 and 802.16 systems is presented. In Section III the working features of the IEEE 802.16 standards are described; in Section IV we introduce the relevant features of IEEE 802.11 standards. In Section V we obtain the analysis of coexistence with simulation set up. In Section VI results are provided and finally in Section VII conclusions are given [11]-[14].

II. Co-existence Model between IEEE 802.11(Wi-Fi) and IEEE 802.16 (WiMAX) Standards

In general, investigation on co-existence of wireless systems needs understanding of interference generated by one system to other. However, the interference among users of non-heterogeneous and co-existing spectrum sharing systems is avoided or managed by dynamic frequency allocation and power control. In this context, we assume the finite power transmission by the nodes leading to formation of circular cells as in Fig. 1. The coverage area of a particular system is a function of transmit power and the nominal receiver sensitivity. Furthermore, this system may cause the interference to the receiver at far away distance from its coverage i.e. the received interference is such that the CIR of

Manuscript received September 6, 2021; revised December 3, 2021.

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DOI: 10.7763/IJCTE.2022.V14.1312

the received signal is less than the nominal receiver sensitivity. This region is defined as the potential interference region as shown by the large circle in the Fig. 1. The spatial overlap of two systems coverage regions is defined as overlap region and the area shown as a Lune is defined as interference region within which the received power by the receiver is below its desired CIR [15]-[19].

In co-existence scenario, the two spectrum sharing system's coverage areas overlap and cause interference to each other. This needs coordination between them to avoid interference. However, overlap in coverage areas does not imply overlap interference regions.

Potential interference region overlap the coverage area which for the interference regions in which spectrum can be shared without any coordination. However, this causes interference leading to loss of spectral efficiency. Hence, the nodes in the interference region can be considered as 'hidden nodes'.

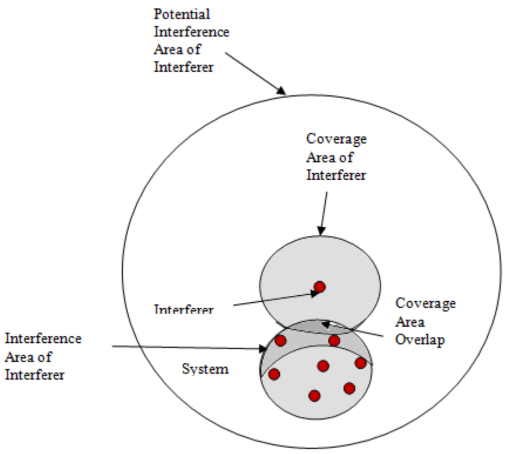


Fig. 1. Coexistence system geometrical model.

As can be seen from the geometric model in Fig. 1 wherein the interfering system which co-exists with other system may be heterogeneous or non-heterogeneous. From this model, we can have some basic assessment of possible impact of the interference [15], [16].

It can be visualized that in the coverage region spectrum sharing with the help of coordination is possible using the access protocols such as CSMA/CA. The connectivity of the nodes can be increased by allowing increase in transmit power. However, it leads to two effects: i) Firstly, the increase in the coverage overlap, which may cause loss of spectral efficiency. ii) Secondly, the reduction of the amount of interference region inside the coverage region, which may cause reduction in the area where coordination is possible. This implies that if the coexisting system employ the spectrum sharing protocol help increase the spectral efficiency [17], [18].

III. IEEE 802.16 (WiMAX) Standard

IEEE 802.16 [1] is a WiMAX radio standard, which uses the frequencies between 2 and 11 GHz for its operation. It has four different Physical layers and point coordinated MAC layer. IEEE 802.16 standard has one central Base Station (BS) and multiple associated Subscriber Stations (SS) referred as centralized architecture [1], [12], [18].

The WiMAX 802.16 is a Standard use point coordinated MAC layer controlled by Central access point. The standard only uses the entire spectrum due to its point coordination function. The IEEE 802.16 uses twelve channels each of 28MHz in the unlicensed spectrum of 5 Ghz band [20]. The IEEE 802.16 coexists with other standards only by manual channel selection [12], [15].

The IEEE 802.16 standard uses both time duplex division (TDD) and frequency duplex division implementations in license spectrum whereas in license free spectrum such as 5Ghz it uses only time duplex division (TDD). The frame structure of IEEE 802.16 is given in Fig. 2. The initial broadcast packet contains the information of downlink and uplink slots of recipient, the length and position of contention period which contains the information of bandwidth requirement. Due to nonscheduled transmission in contention period, the nodes request extra bandwidth to the central coordinator [12], [13], [16]. It provide guarantee of resource allocation for every transceiver frame, support different possible classes of connections from best effort to unsolicited grant service and also it decide [14], [17] whether the coordinator has capacity to provide the services in connection time otherwise connection is disconnected.

Due to centrally controlled transmission power, scheduling and modulation, the IEEE 802.16 Standard can achieve 85% to 90% efficiency. The 802.16 covers large area and supports non line-of-sight operation [20], [21].

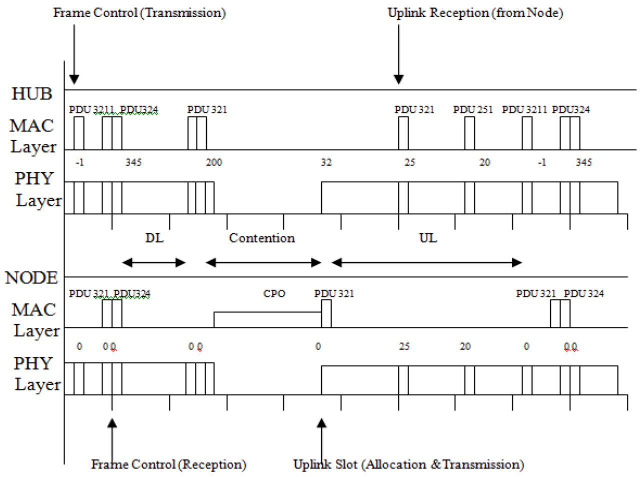


Fig. 2. The frame format of IEEE 802.16 standard.

IV. IEEE 802.11(Wi-Fi) Standard

The wireless standard IEEE 802.11 (Wi-Fi) uses carrier sense multiple access with collision avoidance (CSMA/CA) protocol for its Medium Access Control (MAC) layer and optional Ready to Send/Clear to Send (RTS/CTS) protocol handshaking mechanism. The Distributed Coordination Function (DCF) includes RTS/CTS handshaking mechanism allow wireless users fair sharing of the wireless medium [2].

The carrier sense multiple access with collision avoidance (CSMA/CA) protocol defer transmitter to the next available transmission slot when the channel medium contain power more than certain threshold value. The sensed transmission from a compatible node is decodable and includes header information of start of next available slot. When a number of compatible nodes try to transmit on the same transmission slot to allow [4] contention between them then according to the standard rules, each node select different random backoff to transmit and the node with lowest backoff is allowed to transmit first [21].

When the medium sensed interference is not decodable then it uses another energy sense threshold value which is 20 dB more than nominal sensitivity levels to decode the packets. This provides serious impact on the protocol as well as on simulation results [10].

The 'hidden node' problem is solved by protecting data transmission both at transmitter and receiver with the use of CSMA/CA protocol and RTS/CTS protocol handshaking mechanism.

The IEEE 802.11 (Wi-Fi) standard has drawback of poor efficiency due to significant overheads on every data exchange at nodes. The overheads are RTS-CTS delays, random backoff intervals, DCF Inter Frame Space (DIFS) periods, Acknowledgement (ACK) overhead for different QoS. The Fig. 3 shows IEEE 802.11 data exchange where interval of actual data transmission is less than half of the total length of data exchange [21].

If number of nodes competing same slot is large then efficiency goes on decreasing and increases the probability of backing off to the same slot where the information packet collisions occur. The reason behind the packet collision is either due to interfering transmission less than receiver sensitivity level or due to used different scenarios of receiver and transmitter which is solved with the help of RTS/CTS protocol [8], [10].

Data transmission with CSMA/CA mechanism is not efficient. The IEEE 802.11 standard uses Point Coordination Function (PCF) for node to schedule data packets, which improves efficiency, but the PCF is not compatible in terms of coexistence scenarios of different wireless technologies.

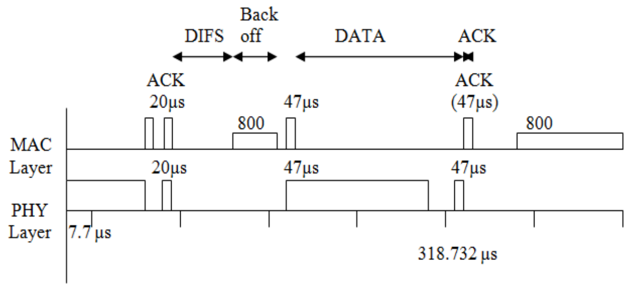


Fig. 3. Data Exchange of IEEE 802.11 Standard.

V. Analysis of Coexistence: Simulation Set up

Simulations are carried out to analyze the impact of interference from one system to another. Here we consider coexisting IEEE 802.11 and IEEE 802.16 systems. The simulations are carried out in NS2. The PHY layer of both the system is considered to be OFDM based and captures packet level dynamics. The basic physical layer parameters considered for both the systems are same which simplifies the simulation environment. Simulation parameters are summarized in Table I.

Some of the key parameters are varied especially for IEEE 802.11 are : 1) RTS/CTS- This may be used or not used, 2) Energy threshold E_t (decibel) for non-compliant packets is taken to be above sensitivity threshold by +0dB or +17dB (E_t=0dB indicates deferral of WiMAX IEEE 802.16 packets by Wi-Fi IEEE 802.11 packets same way for other Wi-Fi IEEE 802.11 packets and E_t=+17dB indicates deferral of Wi-MAX IEEE 802.16 packets when their power is 17 decibel above the receiver sensitivity), 3) Connectivity a) Minimum connectivity- Transmit power just above receiver sensitivity for receiver at 500 m b) Full Connectivity- transmit power +6dB above minimum connectivity transmit power and the separation between two systems is varied from 50 m to 1500 m.

TABLE I: Simulation Parameters

Sr. No.	Parameters	Values
01	Cell radius	500m
02	Number of nodes per system	50 (excluding the hub)
03	Required CIR for Threshold	>10dB
04	Path loss exponent	2.4
05	Shadowing	0dB
06	Carrier frequency	5.8GHz
07	Bandwidth	20MHz for both IEEE 802.11 and IEEE 802.16
08	Modulation(s)	QPSK only
09	FEC	½ rate
10	Datarate	1 bits/sec/Hz
11	Minimum sensitivity	-79dBm
12	Packet length	2000 Bytes

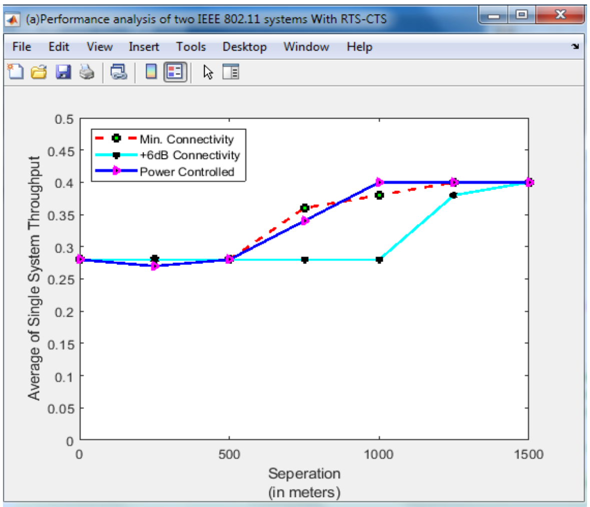
The IEEE 802.16 power control is switched off, since efficiency is not affected by the connectivity above minimum level. The coexistence scenarios are considered in simulations are: 1) Two IEEE 802.11 systems, 2) two IEEE 802.16 systems and 3) IEEE 802.11 and IEEE 802.16 systems. The offered loads for different coexistence scenarios is given in Table II.

TABLE II: Offered Load for Coexistence Scenario

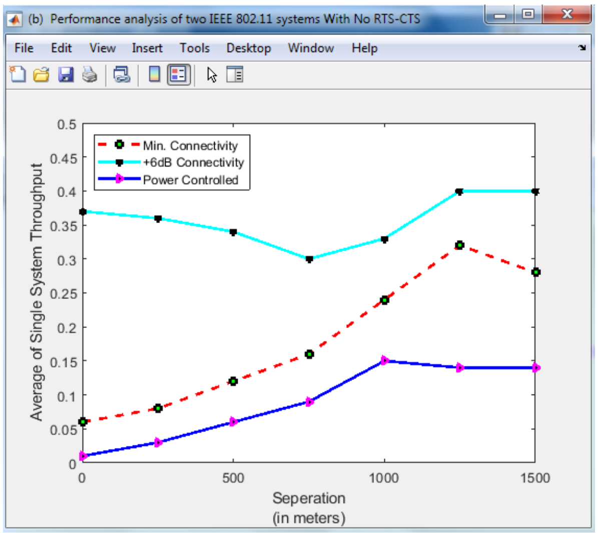
Sr. No.	Load/Scenario	802.11 & 802.11	802.16 & 802.16	802.11 & 802.16
01	Load with RTS/CTS	L_{Max} = 0.55	L_{Max} = 0.88	L = 0.4
02	Load without RTS/CTS (Full Connectivity)	L_{Max} = 0.7	--	L = 0.4

VI. Performance Analysis of Coexistence without Interworking

As mentioned above, the simulations are carried out in three scenarios a) two IEEE 802.11 systems, b) two IEEE 802.16 systems and 3) IEEE 802.11 and IEEE 802.16 systems. The results in Fig. 4a, 4b shows the average single system throughput for two IEEE 802.11 systems with and without RTS/CTS respectively at different system separations with minimum connectivity, full connectivity and power control. Fig. 4a shows that the single system average throughput with minimum connectivity and power control fairly tend to achieve 40% near to the 50% limit for a single system. However, the full connectivity (transmit power +6dB above minimum connectivity) mode needs more separation, i.e. it generates mutual interference at close proximity of the systems than the fair sharing. For the case of no RTS/CTS mode as in Fig. 4b, in case of minimum connectivity and power control the system performance is not good; however, full connectivity mode performs well except at 600m separation, the performance lowers slightly due to largest common interference area.



(a) Performance analysis of two IEEE 802.11 systems with RTS-CTS



(b) Performance analysis of two IEEE 802.11 systems with no RTS-CTS

Fig. 4. Performance analysis of two IEEE 802.11 systems for (a) With RTS-CTS, (b) No RTS-CTS.

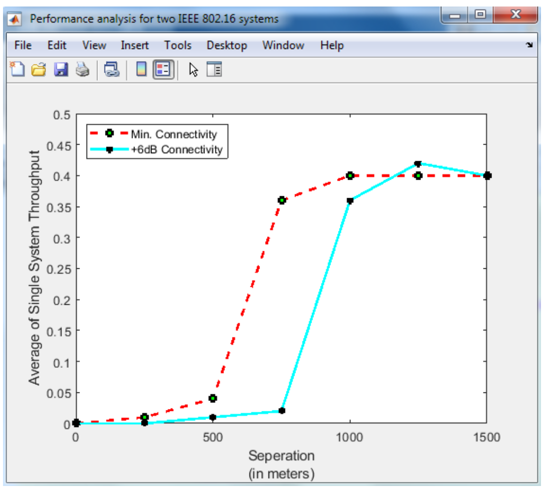
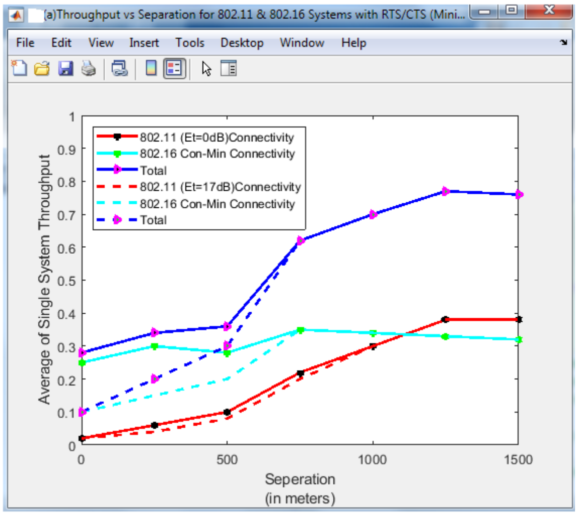
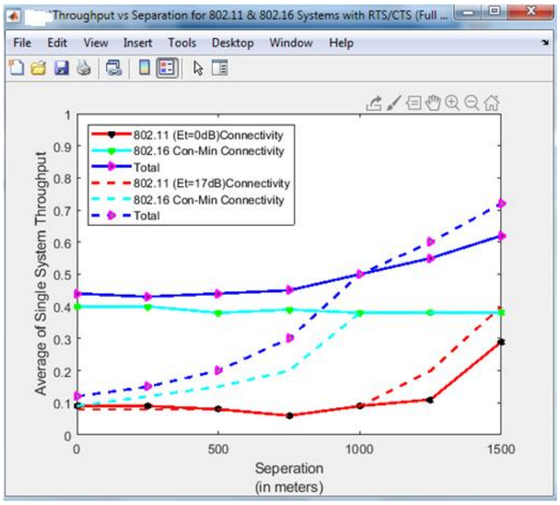


Fig. 5. Performance analysis for two IEEE 802.16 systems.

Fig. 5 show the results for two IEEE 802.16 systems, where in power control is switched off which is not necessary. In this case, unlike in IEEE 802.11, the single system throughput increases sharply from virtually no throughput to 40% as separation increases. But for lower separation, though IEEE 802.16 can have capacity at L=0.4 loading, the throughput reduces almost to zero.



(a) Throughput vs Separation for 802.11 & 802.16 Systems with RTS/CTS (Minimum connectivity)



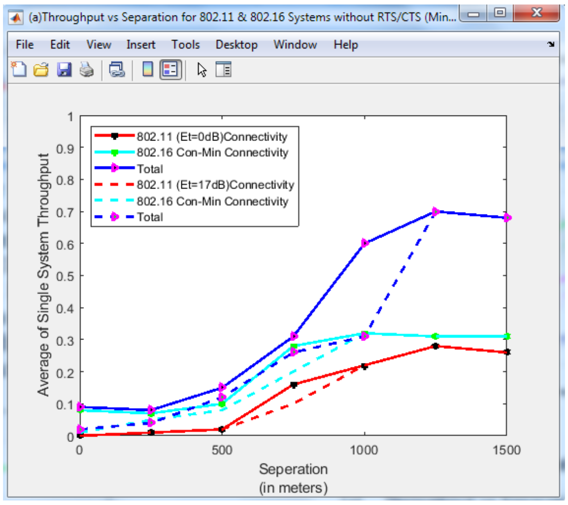
(b) Throughput vs Separation for 802.11 & 802.16 Systems with RTS/CTS (Full connectivity)

Fig. 6. Performance analysis of IEEE 802.11 and IEEE 802.16 systems with RTS-CTS for (a) Minimum connectivity (b) Full connectivity.

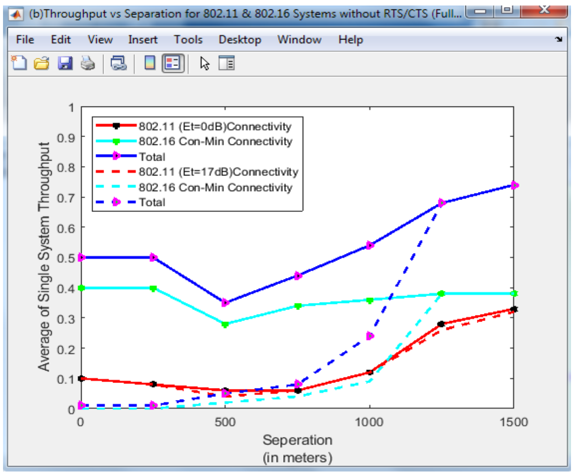
The results for the third scenario for one IEEE 802.11 and other IEEE 802.16 is as shown in Fig. 6 and Fig. 7. The results on average single system throughput using RTS/CTS with minimum connectivity and full connectivity are shown in Fig. 6a and b, respectively. Two set of curves are presented in each of the plot one corresponding to E_t=0dB (indicates deferral of IEEE 802.16 packets by IEEE 802.11 packets same way as for other IEEE 802.11 packets) and E_t=+17dB (indicates deferral of IEEE 802.16 packets only if their power is 17 dB above the receiver sensitivity). In Fig. 6a, the results for average single system throughput with minimum connectivity is reduced in general for all cases and more severely for E_t=+17dB case- the achieved throughput for IEEE 802.16 systems drops to about 25% of the offered load and IEEE 802.11 to 12%. With full connectivity and with

RTS/CTS as shown in Fig.-6b, IEEE 802.16 throughput is unaffected by the presence of IEE 802.11, however, with E_t=+17dB it gets affected at lower separation.

Similar results as in Fig. 6 are indicated for the case with no-RTS/CTS as shown in Fig. 7.



(a) Throughput vs Separation for 802.11 & 802.16 Systems without RTS/CTS (Minimum connectivity)



(b) Throughput vs Separation for 802.11 & 802.16 Systems without RTS/CTS (Full connectivity)

Fig. 7. Performance analysis of IEEE 802.11 and IEEE 802.16 systems with no RTS-CTS for (a), Minimum connectivity (b) Full connectivity.

VII. Conclusion

In this paper we have used performance analysis of coexisting homogeneous and heterogeneous multiple systems to show the impact of interference to each other. It can be seen from the results that IEEE 802.11 under coexistence almost reaches its single system average throughput under minimum and full connectivity especially when RTS/CTS is used, however, under power control mode it requires larger separation to attain the similar performance. On the other hand, IEEE 802.16 achieves the nearly 50% throughput at the separation of just more than cell radius when we use minimum connectivity mode, however, for full connectivity mode the separation required is larger. Under heterogeneous coexistence scenario with RTS/CTS in IEEE 802.11, IEEE 802.16 systems performance does not suffer however, without RTS/CTS it suffers little at especially 500m separation. Overall, both systems suffer without RTS/CTS and full connectivity mode.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

R. H. Adekar, as a research scholar conducted the research under the supervision of A. K. Kureshi who analyzed and verified the research. Both authors agree with the final version of the manuscript.

Acknowledgment

First, my appreciation goes to my parents and family for their sacrifice, commitment, and overall, their support and consistent encouragement. I wish to express my sincere thanks with gratitude to my Ph.D. supervisor Dr. A. K. Kureshi for his continuous help and guidance in completing this research paper. I wish to express my sincere thanks Dr. M. M. Deshmukh for his encouragement and support. I wish to express my sincere thanks to the Director, National Institute of Electronics & Information Technology, Dr. Babasaheb Ambedkar Marathwada University, Aurangabad for his continuous support and encouragement to complete the research program requirements.

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