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MAC Protocol with Adaptive Power Management in Multi-Channel Multi-Radio Wireless Networks

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Abstract: Power control is one of the essential technical of energy aware Mobile Ad-hoc Networks (MANETs) and has gained much attention. Power control can reduce energy consumption but it also brings more collisions and frequent changes of network topology. In this project, we propose a comprehensive solution for power control in Mobile Ad-hoc Networks. Our solution emphasizes the combination on both power control and multi-channel and combination on the MAC layer and network layer. Our solution is characterized by the following features: it uses independent channels to transfer data packets to reduce collisions in data transmission, it uses maximum power level to transfer control packets and proper power to transfer data packets, as a result energy consumption is reduced, network connectivity is guaranteed and frequent change of network topology is eliminated at the same time, this idea inspired from POWMAC and PCDC protocols. It employs POWMAC protocol which is intended to allow for multiple transmissions to take place within the same neighborhood that leads to an increase in network throughput and possibly a reduction in the overall energy consumption. This protocol provides proper solution to the hidden and exposed terminal problem in wireless ad hoc network and improves the network performance. The performance of MC-POWMAC protocol is tested. Experiments show that MC-POWMAC protocol is suitable to solve the problem of hidden and exposed terminal in multi-hop wireless networks and can control the power more effectively to reduce the energy consumption of network nodes for prolonging the life of the entire network. Simulation results emphasize that the performance of MC-POWMAC is better than that of POWMAC and 802.11 where we increased the throughput from 50% in POWMAC to 74% in our suggested protocol.

Key words: MAC protocol, multi-channel, multi-radio, wireless networks, simulation

INTRODUCTION

A mobile ad hoc network (MANET) is a group of wireless mobile nodes that can dynamically form a network to exchange information without using any pre-existing fixed network infrastructure. This is a very important part of communication technology that supports truly pervasive computing, because in many contexts information exchange between mobile units cannot rely on any fixed network infrastructure but on rapid configuration of a wireless connections on-the-fly. Wireless ad hoc networks themselves are an independent, wide area of research and applications, instead of being only just a complement of the cellular system (Omari and Sumari, 2010).

Mobile ad hoc network is an autonomous system of mobile nodes connected by wireless links. Each node operates not only as an end system but also as a router to forward packets. The nodes are free to move about and organize themselves into a network. These nodes change position frequently (Sandeep and Dwivedi, 2015). To accommodate the changing topology special routing algorithms are needed. For relatively small networks flat routing protocols may be sufficient. However, in larger networks either hierarchical or geographic routing protocols are needed. There is no single protocol that fits all networks perfectly. The protocols have to be chosen according to network characteristics such as density, size and the mobility of the nodes. MANET does not require any fixed infrastructure such as a base station, therefore, it is an attractive option for connecting devices quickly and spontaneous. Mobile ad hoc network used alone (ex. in the military) or as a hybrid together with the Internet or other kind of networks. The difference in MANET applications has results in different requirements and hence various routing protocols may be suitable in

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different areas. Network size and the frequency of the change in topology are factors that affect the choice of the protocols. So there is no perfect protocol for all these kind of applications. As a result of that there is still several investigations and research on MANET networks which may lead to even better protocols or new challenges (Barati *et al*., 2012).

Several techniques, algorithms and protocols have been developed for developing and evaluating the communication during the past century. The earlier multi-channel MAC protocols adopt fixed channel allocation mode by using different band width or spreading frequency codes to divide the single channel into multiple sub-channels. These protocols yield to reduce collision effectively, in the other hand the complexity increased in addition to the cost and energy consumption (Raghuvanshi *et al*., 2015).

The traditional known multi-channel MAC protocols based on fixed channel allocation algorithm and required more expensive and complicated hardware. As a result of implementing on the applications of multi-channel and dynamic channel assignment technology; the problem of hidden and exposed terminals are completely solved, in addition to that channel distribution, access control, collision and competition issues solved effectively and overall the network capacity increased significantly, besides an improvements in the performance and network life (Conti, 2014).

In this project, we design a multi-channel power control MAC protocol used half-duplex single transceiver where the idea of this project inspired from POWMAC and PCDC protocols which is compatible with the standard IEEE 802.11 physical layer of wireless ad hoc networks as well as power control capability. So, the aim behind this project is developing a methodology which can improve the communication among mobile ad hoc networks by using multi-channel system and reducing the power consumption through using transmission power control protocol POWMAC.

Power control techniques in ad hoc networks: Power consumption in ad hoc networks can be controlled either by controlling the transmission power or by selecting the optimal routs for data transmission. Power control over data transmission affects all layers of the OSI model from physical layer to transport layer. In general there are two categories of conservative power protocols as transmitter power control protocols and power management algorithms and the last class can be also divided into MAC layer protocols and network layer protocols (Muhammad and Mahmood, 2011).

Related work in power control protocols: Recently, research related to power control can be categorized into three classes: the first class of related works is based on network layer, in which power is used as route metrics. For a given threshold received power Pr, the minimum power that must be transmitted Pt for a successful reception, under the condition of no fading, can be given as:

$$P_r = P_t \frac{K}{d^{\alpha}} \qquad (1)$$

where, K is a constant, d is the distance between the two nodes and $\alpha \geq 2$ where α is the path loss exponent ($\alpha = 4$). According to above principle, execute minimum power route protocol based on Dynamic Source Routing protocol (DSR) or a table of driven routing protocol (Gomez *et al*., 2003; Doshi *et al*., 2002). But the exchanges of data through under these protocols are not extremely precise due to nodes movement (Kawadia and Kumar, 2003). It has been demonstrated that CLUSTERPOW technology combines the three important concepts together which are the power control, clustering and routing technology. This protocol generates additional overhead because of high power consumption and too much bandwidth occupation. In addition to that the power control under these circumstances produce additional hidden terminal problem and decrease network performance noticeably.

The second class is based on modification of MAC layer. The algorithm permits the node to determine the level of transmitted power in RTS and then the desired transmitted power is sent back in the CTS. While receiving the CTS, the transmitter then exchanges DATA using the power level determined in CTS. This algorithm lets the receivers to help the transmitter to choose the proper power level to maintain a desired signal-to-noise ratio. While the scheme is improved in that it used RTS-CTS messages and the transmitter used the maximum level of power periodically during data transmission so that nodes in the Connection Set Zone (CS-Z) can detect of the channel the used to avoid collision (Pursley *et al*., 2000; Jung and Vaidya, 2002). While the schemes in other studies (Wu *et al*., 2000; Monks *et al*., 2001) introduced a Busy Tone solution as a power control factor to get rid of the hidden terminal problem but this solution increase the power consumption.

The third and last class depends on the interaction between MAC layer and network layer. This can be shown in PCDC protocol (Muqattash and Krunz, 2005) in which it has been proposed Power Controlled Dual Channel (PCDC) protocol that emphasizes the interaction between the MAC and network layers. PCDC described that the MAC layer indirectly influences the selection of the next-hop by adjusting the power of route request packets under the condition of network connectivity. Channel gain obtained from RTS and CTS packets exchange which is used to build the network topology. They have used Collision Avoidance Information (CAI) to bind the transmission power of the interfering nodes in the vicinity of a receiver.

Muqattash and Krunz (2005) have proposed POWMAC: a single-channel power-control protocol for power control and throughput enhancement in wireless Ad Hoc networks. POWMAC uses an Access Window (AW) to allow a series of (RTS-CTS) exchanges to be performed before several concurrent data packet transmissions can be started. The length of the AW adjusted based on the number of node connection set for multiple interference-limited concurrent transmissions to take place in the same vicinity of a receiving terminal. However, the implementation of synchronization between nodes within the Access Window (AW) is very difficult and the interference problem not solved either.

Related work in multi-channel: In this study, we reviewed some of the protocols which are related to multi-channel MAC protocols which allow concurrent connections to transmit exploiting the orthogonal channels from the channel bank which in turn reduced collisions and increased the network throughput.

Multi-channel MAC protocols: In the following, we reviewed the most notable MAC protocols proposed in the literature for multi-channel wireless ad hoc networks which in turn, used to enhance the performance of wireless ad hoc networks, since each node can use multiple channels to get rid of collisions and increase the spatial reuse. A multi-channel MAC protocols may belong to one of the following categories.

Multi-channel single-transceiver MAC: This type of protocols is used in our work here where in each node, just one transceiver is available and so that only one channel is active at any time toward the wireless node. However, within multi-channel system, different nodes may operate simultaneously on different channels to improve system capacity.

Multi-channel multi-transceiver MAC: In this type of protocol, there is only one MAC layer coordinates the functions of multiple channels on the top of the physical layer. So, a radio includes multiple parallel RF front-end chips and baseband processing modules to support several simultaneous orthogonal channels.

Multi-radio MAC: In this type, network nodes are supported with multiple radios, each with its own MAC and physical layer. And the communications in these radios are totally independent. Thus, a virtual MAC protocol such as the Multi-radio Unification Protocol (Adya *et al*., 2004) or the Hybrid Multi-Channel Protocol (Kyasanur and Vaidya, 2006) is needed on top of the MAC layer to coordinate communications in all channels.

MATERIALS AND METHODS

Multi-channel single-transceiver MAC protocols: This class of MAC protocols used in this project. It uses a single channel interface that can be tuned dynamically on different channels from the channel bank. However, as result of implementing this type of protocols; a new type of hidden terminal problem can be appeared known as multi-channel hidden terminal problem. Let us suppose that we have N orthogonal channels; one them is dedicated to the exchange of control messages (RTS/CTS/DTS), the other channels is assigned for data exchanging. So, if any node is not exchanging data, it listens to the signaling channel; on the other hand, if a node is exchanging DATA/ACK packets through a data channel, it becomes deaf for the RTS/CTS packets which sent by other nodes that tries to transmit, thus using the same data channel may cause a collision. So, we try to solve this problem in our proposed protocol (MC-POWMAC).

The hop reservation multiple access MAC is a multi-channel, frequency hopping spread spectrum protocol. Network nodes select a channel from the channel bank according to a predefined hopping pattern. Then after the agreement between any two nodes to communicate, they tuned on the same frequency and the other nodes continue hopping within the spectrum so that multiple, concurrent transmission can occur on different channels. However, such protocol can be implemented only to frequency hopping networks (Yang and Aceves, 1999).

The Multichannel MAC protocol (MMAC) which was proposed by So and Vaidya (2004). This protocol needs only one transceiver per node and tries to solve the multi-channel hidden terminal problem by implementing a per nodes synchronization. MMAC operates as follows: nodes periodically listen to a common control channel, argue to select the channel and then move to the selected channel. However, several problems in MMAC protocol have not been solved, like global synchronization and the channel assignment algorithm not active which affects the network performance and above that the packet delays is large even for a single hop. And although MMAC eliminates multi-channel hidden nodes problem, it generates several exposed nodes.

SSCH algorithm operates as a single-interface and virtual MAC protocol. In this algorithm a pseudorandom procedure decides which channel to be selected every time slots. The procedure (which used by any two nodes) is guaranteed to overlap periodically to ensure communication between any to nodes within the CS (Bahl *et al*., 2004).

The Load Based Concurrent Access Protocol (LCAP) was proposed by Arora and Krunz (2007) with directional antennas which used packet-based power control algorithm to increase the channels reuse by allowing interference-limited, concurrent directional transmissions within the same vicinity. In this protocol a separate control channel is assigned for minor-lobe interference while the RTS is sent by Omni directional antenna and CTS/DATA/ACK packets are exchanged directionally. This can reduce the number of terminals be informed in current transmission to get rid or reduce the effect of hidden terminal problem.

Multi-channel multi-transceiver MAC protocols: In this type of protocol, a radio contains several parallel RF front-end chips and a module for baseband processing to support the presence of several simultaneous channels. While only one MAC layer presents over the physical layer to control and regulate the multiple channels operation.

In the study of Nasipuri *et al*. (1999), the multi-channel CSMA protocol used single control channel and N orthogonal data channels. So through control packets we can decide the best channel to send the data packet on. There are a drawback for this protocol related to a large number of interfaces needed (one for each channel) which is an expensive solution.

In the study of Kyasanur *et al*. (2005), the Control Channel based MAC Protocol (C2M) which allows concurrent channel contention and data transmission. This algorithm is executed by combining advance reservation on the control channel and data aggregation on the data channel.

In the study of Pan *et al*. (2007), a Dynamic Channel Assignment with Power Control MAC protocol (DCA-PC) is proposed which somehow likes our proposed protocols. DCA-PC is a multichannel MAC protocol that in it a power control algorithm implemented to reduce the interference generated on the data channel. Each node in this algorithm equipped with two interfaces: control channel dedicated for control messages exchanging while the other can be tuned to different channels for data exchanging based on a Free Channel List (FCL) which is included in the RTS message. In addition, RES message is used to reserve the data channel. The DCA-PC scheme does not exploit the spatial reuse made possible by the utilization of directional antennas.

Multi-radio MAC protocols: In this type of protocols each nodes equipped with by multiple wireless network interfaces, so each node has its own MAC and physical layer. Multi-radio Unification Protocol (MUP) is proposed which equipped with multiple interfaces, tuned on orthogonal and fixed channels. This protocol costs a lot when several channels are presented. In addition to that, the hidden terminal problem is not solved completely and above the all, a packet re-ordering may occur causing low end-to-end throughput (Adya *et al*., 2004).

At the last, the Hybrid Multi-Channel Protocol (HMCP) is proposed in which each node has at least two interfaces. One interface is tuned to a specified fixed channel and the other interface can switch between the remaining channels. HMCP tries to ensure that the number of nodes using each fixed channel is balanced. Each node advertises its fixed channel using broadcast hello packets (Kyasanur and Vaidya, 2006).

The multichannel power control protocol MC-POWMAC

Assumptions: We consider a mobile Ad Hoc network consist of N nodes where each node is equipped with a single transceiver that can be tuned to any of the available M channels where N>>M. In our protocol design, we assume that we have an Orthogonal channels where the total number of available orthogonal channels is M. One channel is used as control channel M_c, used for transmitting RTS and CTS messages while the other M_D = M-1 channels are used for data exchange, including the acknowledgment packets where M_D<<U, U is the total number of users (active nodes). Also we assume that the channel gain is stationary for the transmission duration of a few controls and for one ensuing data packet. This assumption holds for typical mobility patterns and transmission rates. The gain between two nodes is assumed the same in both directions, the data and control packets between a pair of nodes observe similar channel gains and also a two-ray propagation model is assumed, also we assumed that the radio interface can provide the MAC layer with the average power of a received control signal, as well as the average interference power, such measured values using SINR estimators and each terminal is equipped with one transceiver that has standard carrier-sense hardware (i.e., a basic IEEE 802.11-compliant transceiver). Also we assume that the antenna used is a monopole antenna has an Omni directional radiation pattern. That radiates equal power in all azimuthal

directions perpendicular to the antenna but the radiated power varies with elevation angle with the radiation dropping off to zero at the zenith, on the antenna axis the radiation pattern of the antenna can be divided into M non-overlapping sectors, each of width equal to 360 M^{-1} degrees (Abasgholi *et al*., 2008). In addition to the above assumptions, we assume that the radio interface can provide the MAC layer with the average power of a received control signal as well as the average interference power. The radio interface is equipped with a carrier sense hardware that senses the control channel for any carrier signal. No carrier-sense is needed for the data channel.

MC-POWMAC overview and design considerations: The main challenges in designing MANETs are to provide high-throughput, reliable and low-complexity wireless access to mobile terminals. The scheme proposed in this project is intended to allow for multiple transmissions under power controlling to take place within the same neighborhood to increase network throughput and to get a reduction in the overall energy consumption. MC-POWMAC scheme is based on a multi-channel, single-transceiver approach, to provide a significantly higher network throughput than the IEEE 802.11 scheme while yet preserving the collision avoidance properties of the IEEE 802.11 scheme. Our scheme based on POWMAC protocol in controlling the concurrent transmission under power control within multichannel to affect the throughput of a MANET networks relative to the IEEE 802.11 scheme and that supports link-layer reliability. Also, we inspired the idea of specific control channel for transaction the control messages (RTS/CTS/DTS) before the data transmission to control the concurrent multi transmission without any collision under power control.

MC-POWMAC protocol is a distributed, asynchronous and adaptive to channel changes. It has the following key features. First, MC-POWMAC does not use the RTS/CTS handshake for silencing terminals in its vicinity; it allows multiple concurrent transmissions to be performed simultaneously. Instead, MC-POWMAC uses Collision Avoidance Information (CAI) (Muqattash and Krunz, 2005) within the control packets to bind the transmission power of potentially interfering terminals in the vicinity of a receiving terminal. Second, each pair of terminals is forbidden from starting data exchange, after the end of control packets handshaking, for certain duration, referred as the Access Window (AW) to allow several pairs of neighbored nodes to exchange their control packets such that data transmissions can proceed concurrently where the number of access slot within the access window is adjusted to allow several terminals to contend for the channel occupation. Third, control packets (except RTS) (CTS/DTS) are exchanged with an adjustable power level within the interference margin to reduce the likelihood of collisions with nodes in its vicinity.

As we mentioned before, access window AW consists adjusted number of fixed-duration access slots which equal the number of Nodes pair (N) that may exchange data. The AW is needed for two reasons. First, it reduces the likelihood of collisions between control Packets (RTS) which transmitted at maximum power. The second purpose of the AW is informing nodes that are exchanging data of the ensuing data transmission to get rid of the deafness problem while transmitting.

We conclude this section with an example that illustrates the basic operation of MC-POWMAC (Fig. 1). The network topology is the one shown in Fig. 2. Consider a configuration with more than four terminals (say: A, B, C, D) where terminals A and C want to communicate with terminals B and D, respectively and there are a bank of channels (say C1, C2 ,C3,…..) such that one channel is used as control channel for (RTS/CTS/DTS) exchange and several channels for data transmission (Fig. 3). Since, each terminal is equipped with single transceiver which can be tuned to the control

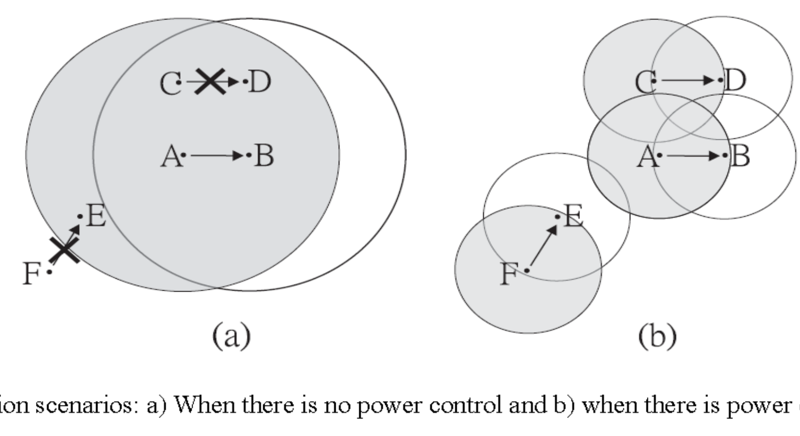

Fig. 1: Transmission scenarios: a) When there is no power control and b) when there is power control

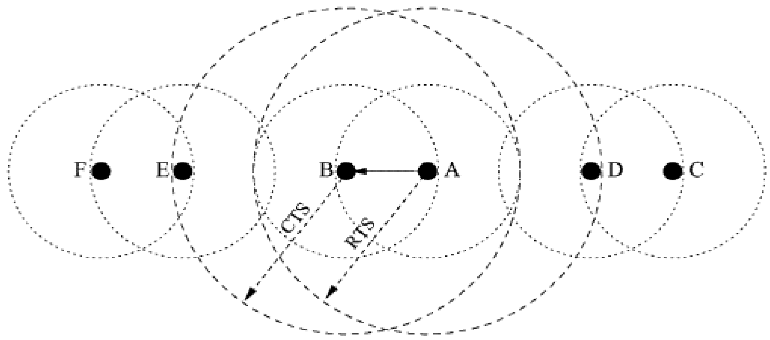

Fig. 2: The basic operation of MC-POWMAC

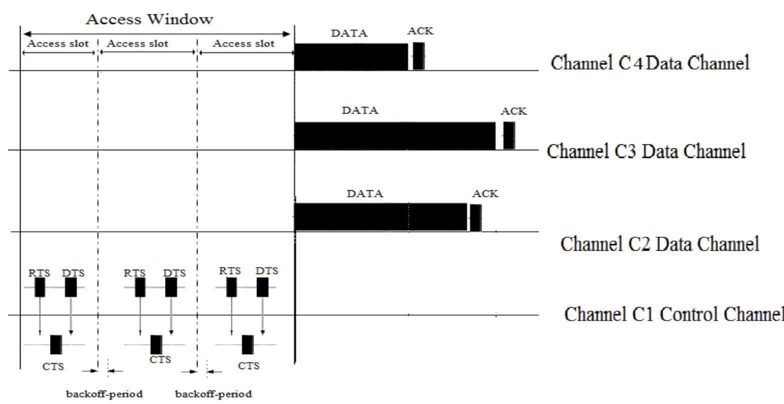

Fig. 3: Time diagram of the operation

channel and then the allocation of independent data channels (suppose 4 data channels) over which data can be exchanged. The communication process proceeds as follows.

Terminal A sends an RTS packet to B at maximum Power (P_{max}) within the control channel which contains several information, related to power calculations like the maximum allowable power ($P_{MAP}^{(i)}$), slot window number $N_{AW}^{(A)}$, Transmission time, ACK Time. Upon receiving the RTS packet, B responds by sending a CTS packet at an adjustable power containing the following information: The power needed to perform the communication $P_{POWMAC}^{(AB)}$, the maximum tolerable interference power $P_{PTI}^{(A)}$, slot window number $P_{AW}^{(A)}$, Transmission time, ACK Time, Channel Usage List (CUL) (channel used from the channel bank) also it contains information about the Free Channel List (FCL), in addition to that the data rate must be supported also within the control channel that reaches all and only potentially interfering terminals. The CTS packet reflects B's willingness to receive a data packet from A under the channel and system requirements.

This RTS/CTS handshake allows A and B to agree on the transmission power, rate, data channel that will be used for the data packet exchange. It also provides a way to inform potentially interfering terminals (e.g., node C) of the power that they can use without disturbing the scheduled reception of the data packet at B. Terminal A uses a third control packet called DTS (decide-to-send) and send it over the control channel to confirm that the transmission from A-B can proceed. Another purpose for the DTS packet is to inform the neighbors of A with the power level that A will use for transmitting the data packet. This information is important for A's neighbors to determine the possibility of receiving a data packet from other terminals simultaneously while A is transmitting to B.

Moreover, the DTS packet informs potentially interfering terminals of the power that they can use without disturbing the reception of the ACK packet at A. After the RTS/CTS/DTS handshake is done, A refrains from sending the data packet for the remaining slots in the AW then the data exchange may started. After the end of the first AS nodes C and D can exchange control packets to determine whether the transmission from C to D can proceed concurrently with that of A and B on the same channel or choosing other channel from the Free Channel List (FCL).

Interference margin: Every node within the Connection Set (CS) must know the amount of interference it can tolerate for potential transmissions in its neighborhood within the same channel while if the transmission implemented within multiple channels algorithm, this problem will be eliminated. In PCDC (Muqattash and Krunz, 2003), a new strategy was developed to adjust the amount of interference margin dynamically to increase network throughput. A distributed algorithm, inspired from power scaling in cellular (DS-CDMA) was proposed to implement the idea in MANETs where all received power at BS must be the same where the received signal-to-interference ratio (SIR) at a receiving node, say i is given by:

$$SIR^{(i)} = \frac{P_m^{(i)}}{\sum_{n=1, n\neq m}^{N} P_n^{(i)} + \eta + \beta^{(i)}} \quad (2)$$

Where:

$P_m^{(i)}$ = The "desired" received power from all intended transmitting nodes (m)
$P_n^{(i)}$ = The received power from an interfering (unintended) transmitter n
N = The number of active transmitters in the neighborhood of node i
η = The thermal noise
$\beta^{(i)}$ = The interference margin of node i

Increasing channel capacity in ad hoc networks defers from the algorithm implemented in cellular Networks (by increasing $\beta^{(i)}$) since the absence of a centralized control and the presence of overlapped area which prevent nodes from hearing all other nodes while data exchanging. As result of that, the idea of users in Ad Hoc networks refers to the expected number of future users where each node tries to accommodate nodes that are within its connection set whom it may interfere with. To implement power scaling in ad hoc each node use the computed connectivity power $P_{conn}^{(i)}$ to compute the maximum scaling constant $\alpha^{(i)}$ that node i can accommodate (Abasgholi *et al*., 2008):

$$\alpha^{i} = \frac{P_{max}}{P_{conn}^{(i)}} \quad (3)$$

where, α^{i} represents the maximum scaling value (the maximum interference margin) that node i may use to maintain communication with its CS. And the maximum capacity can be achieved by maximizing $\alpha^{(i)}$ but this effects battery life time. As a result of that the ratio of the remaining energy ($E_{remain}^{(i)}$) to the full energy ($E_{full}^{(i)}$) of the battery is used to scale down the value of $\alpha^{(i)}$ as follows:

$$\alpha_{eff}^{(i)} = \max\left\{1, \alpha^{(i)} \frac{\left\lfloor \frac{4\times E_{remain}^{(i)}}{E_{full}^{(i)}} \right\rfloor}{4}\right\} \quad (4)$$

where the value of $\alpha_{eff}^{(i)}$ broadcasted in "hello" packets then the minimum value of all $\alpha_{eff}^{(i)}$ values heard is selected. Suppose $\alpha_{min}^{(i)}$ be this minimum of $\alpha_{eff}^{(i)}$. The object behind that if the scaling factor is made larger than $\alpha_{min}^{(i)}$, then at least one of the nodes that is within the maximum range of node I will be peak-power limited (or battery limited) and will be unable to attain its QoS while conserving its battery energy if it needs to start a communication with one of its connectivity set neighbors (Muqattash and Krunz, 2003).

Channel capacity: To compute the achievable rate over any channel within the channel bank , say C_1, we use the channel capacity concept to an Additive White Gaussian Noise (AWGN) channel with B Hz bandwidth and signal-to-noise ratio S/N is the Shannon-Hartley theorem:

$$C^{(i)} = B^{(i)} \log\left(1 + SIR^{(i)}\right) \quad (5)$$

where, C is measured in bits per second if the logarithm is taken in base 2 or nats per second if the natural logarithm is used, assuming B is in hertz; the signal and noise powers S and N are measured in watts or volts, so the signal-to-noise ratio here is expressed as a power ratio, note that the received Signal-to-Interference Ratio (SIR) at a receiving node i is given by:

$$SIR^{(i)} = \frac{P_m^{(i)}}{\sum_{n=1, n\neq m}^{N} P_n^{(i)} + \eta + \beta^{(i)}} \quad (6)$$

Where:

$P_m^{(i)}$ = The "desired" power at the receiver i from the intended transmitter m
$P_n^{(i)}$ = The received power from an interfering (unintended) transmitter n
N = The number of active transmitters in the vicinity of node i
η = The thermal noise
$\beta^{(i)}$ = The interference margin of node i

From the last two equation we can conclude that:

$$C^{(i)} = B^{(i)} \log\left(1 + \frac{P_m^{(i)}}{\sum_{n=1,n\neq m}^{N} P_n^{(i)} + \eta + \beta^{(i)}}\right) \quad (7)$$

$$C^{(i)} = B^{(i)} \log_2\left(1 + \frac{K^{(i)} P_t^{(i)}}{d^n(\sum P_n^{(i)} + \eta)}\right) \quad (8)$$

Dynamic channel assignment strategy via power control: To improve the performance of multi-channel wireless networks depending on a Dynamic Channel Assignment (DCA) mechanism to perform the most efficient allocation of channels to currently active links. Several DCA techniques have been proposed to improve capacity by reusing channels more flexibly in a multihop network. A link is considered feasible if it satisfies some criterion for reliable communications. The fundamental objectives of these DCA techniques are to: Increase the number of feasible links and hence increase the aggregate network capacity and/or reduce the total transmits power in the network, hence prolonging its lifetime when nodes' battery life is limited.

In the proposed protocol, we apply the idea of Foschini and Miljanic (1995) for DCA, method of integrating power control and channel assignment mechanisms in ad-hoc wireless networks; we make full use of the SINR threshold requirements for each pair wise links in order to find an optimal channel assignment for each pair of links. Furthermore based on the assumption of self-organizing and co-operative nature of ad-hoc networks, we also harness power control constraints via stability and non-singularity conditions so that we can maximize channel reusability and hence increase the number of links sharing the same channel in the network. In short optimal channel assignment of each pair of communicating nodes in this study is directly link to the power control constraints involved. In order to assign the optimal number of interfering nodes that can co-exists so that a feasible power vector can be found within its power limits, we propose two novel ways to find the optimal combination of co-channel links.

RESULTS AND DISCUSSION

Channel access mechanism: In MC-POWMAC protocol, control packets (RTS/CTS/DTS) may provide three operations. First, determining the channel gain from power calculations where through these control packets the following information can be determined: the maximum allowable power ($P_{MAP}{}^{(i)}$), access slot number $N_{AW}{}^{(A)}$ in the access window in the control channel, Channel Usage List (CUL) (channel used from the channel bank), the Free Channel List (FCL), transmission time, ACK time. Second, any receiving node use the CTS packet for notifying other nodes in its vicinity about the power needed to execute data exchanging $P_{POWMAC}{}^{(AB)}$, in addition to that information related to the maximum tolerable interference power $P_{PTI}{}^{(A)}$, access slot number $N_{AW}{}^{(A)}$, Transmission time, ACK time, are transmitted in addition to information about the feasible channel that must be selected from the Free Channel List (FCL) through the DCA algorithm, in addition to that the data rate must be supported so CTS packet reflects B's willingness to receive a data packet from A under the channel and system requirements . A third control packet called DTS (decide-to-send) which sent over the control channel and used to confirm that the transmission from A-B can proceed after selection the proper power, data rate and the channel. Finally, each node keeps listening to the control channel regardless of the signal destination in order to keep track of power needed to perform new data exchange and the used channels from the channel bank. Another purpose for the DTS packet is to inform the neighbors of A with the power level that A will use for transmitting the data packet. This information is important for A's neighbors to determine the possibility of receiving a data packet from other terminals simultaneously while A is transmitting to B. Moreover, the DTS packet informs potentially interfering terminals of the power that they can use without disturbing the reception of the ACK packet at A. After the RTS/CTS/DTS handshake is done, A refrains from sending the data packet for the remaining slots in the AW then the data exchange may started. After the end of the first AS nodes C and D can exchange control packets.

If node say j has a packet to be transmitted, it sends a RTS at Pmax where the data included in RTS packet is: the maximum allowable power level ($MAP^{(i)}$) (among the M possible power levels provided by the hardware) that node j can use without disturbing any ongoing reception in its neighborhood. While the receiver, say node i, uses the predetermined Pmax value to estimate the channel gain Gij. Accordingly, $P_{min}{}^{(ij)}$ which is the power lets the receiver correctly decoding is given by:

$$P_{min}^{ij} = \frac{SINR_{TH} \times (\sum_{n=1,n\neq m}^{N} P_n^{(i)} + \eta + \beta^{(i)})}{G_{ij}} \quad (9)$$

This $P_{min}{}^{(ij)}$ does not allow for any interference margin at node i, so all neighbors of node i will have to defer their transmissions during node i's ongoing reception (5). To allow for a number of future interfering transmissions to take place in its neighborhood, node i requests that node j uses a transmission power that is larger than $P_{min}^{(ij)}$. Specifically, the power that must be used by node j is given by (5):

$$P_{requested}^{(ij)} = P_{POWMAC}^{(ij)} = \frac{SIR_{TH}(\gamma^{(i)} + K^{(i)}P_{noise}^{(i)})}{G_{ij}} \quad (10)$$

where, $K^{(i)}P_{noise}^{(i)}$ is the total interference margin that node i can tolerate from unintended transmitters. When responding to j's RTS, node i indicates in its CTS the power level (among the M possible levels) that is just above $P_{requested}^{(ij)}$. Node i then inserts a share of this value, namely $P_{noise}^{(i)}$, in the CTS packet and sends this packet back to sender j at Pmax over the control channel. The rationale behind inserting a share is to prevent one neighbor from consuming the entire interference margin. The parameter $K^{(i)}$ essentially represents the number of additional concurrent (unintended) transmissions in the neighborhood of a receiver within the same channel:

$$K^{(i)} = \frac{P_{Max}}{P_{conn}^{(i)}} - 1 = \frac{P_{Max} - P_{conn}^{(i)}}{P_{conn}^{(i)}} \quad (11)$$

Where:

$$P_{conn}^{(i)} = P_{POWMAC}^{(i)} = P_{required}^{(i)}$$

If the density of nodes in the region is low, nodes can only communicate with each other using Pmax with a zero interference margin within the same channel or using other co-channels. This means that $K^{(i)}$ has to be zero, connected network $P_{conn}^{(i)} = P_{max}$. We can express $P_{noise}^{(i)}$ in terms of $\alpha_{min}^{(i)}$ as follows:

$$\alpha_{min}^{(i)} \times \frac{SNR_{TH} \times \delta^{(i)}}{G_{ij}} = \frac{SNR_{TH}(\delta^{(i)} + K^{(i)}P_{noise}^{(i)})}{G_{ij}} \Rightarrow \quad (12)$$

$$P_{noise}^{(i)} = \delta^{(i)} \times \frac{\alpha_{min}^{(i)} - 1}{K^{(i)}}$$

Where:

$$\alpha_{min}^{i} = \frac{P_{max}}{P_{conn}^{(i)}} \text{ and } \delta^{(i)} = \sum(P_u^i + P_{Thermal})$$

Performance evaluation and numerical analysis: We evaluate the performance of MC-POWMAC through calculating the throughput, the signal to interference noise ratio, the number of served user and number of blocked user in our scenario by performing extensive simulations under MATLAB simulating language.

Simulation setup: We now evaluate the performance of MC-POWMAC, in terms of network throughput and number of served/blocked users. For simplicity, data packets are assumed to be of a fixed size (2 Kbytes). Consequently, we can concentrate on the one-hop throughput. We use the two-ray propagation model with a path loss factor of 4. Other simulation parameters are given in Table 1. The results are based on simulation experiments conducted using Matlab simulating language.

T-topology network: This scenario consists of 4 nodes which are illustrated in the next Fig. 4, two connections are active: C1 between nodes 1 and 2 and C2 between nodes 3 and 4. We first assume that the number of available data channels (ND) is equal to 1.

In this network layout, MC-POWMAC allows the two connections to be active at the same time, since it uses multi-channels and power control to limit the mutual interference between C1 and C2. On the other hand, all the other MAC protocols activate at most one connection at a time. Table 2 shows the numerical results obtained in this scenario, the total throughput achieved by the two

Table 1: Simulation parameters

Parameters	Values
Data packet size	2 KB
Data rate	1 Mbps
SINR threshold	Rand (1)
Transmission power	0.1-0.4 mW

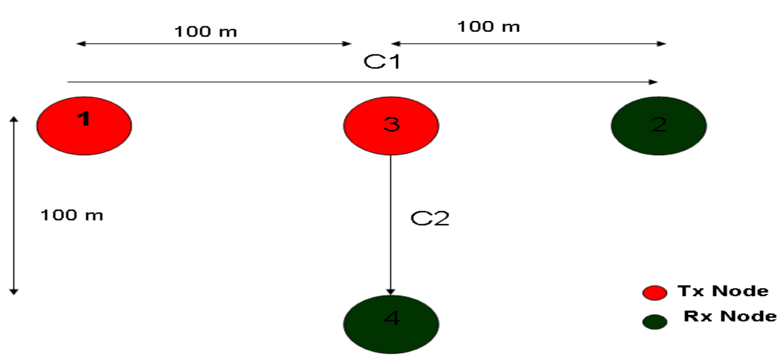

Fig. 4: Network scenario t-topology of 4 nodes with 2 active connections

Table 2: T-topology network: average throughput for all the considered MAC protocols

MAC	Throughput (Kbps)	Percentage of improvements to 802.11 (%)	No. of transmission
IEEE 802.11 MAC	1.1135	-	1
POWMAC	85.9	76.144	1
MC-POWMAC	85.9	76.144	1

Table 3: T-Topology network: average throughput

MAC	Throughput (Kbps)	Percentage of enhancement to 802.11 (%)	No. of transmission
IEEE 802.11 MAC	1.1135	-	1
POWMAC	85.9	76.144	1
MC-POWMAC	171.8	153.29	2

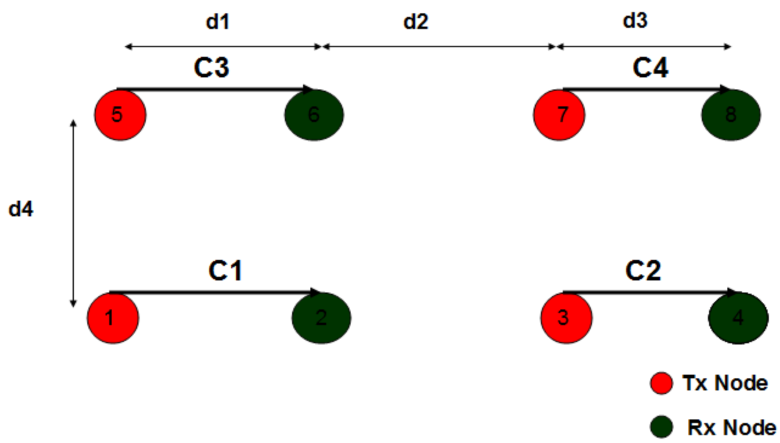

Fig. 5: Eight-node scenario with 4 active connections

connections, number of served users the percentage improvement with respect to the IEEE 802.11 standard MAC and with single channel POWMAC. We observe that MC-POWMAC improves consistently the throughput (up to 75%). This is essentially due to the increased in spatial reuse made possible by the utilization of multiple channels and power control, as well as by the utilization of a separate control channel to inform all network nodes of new data transmissions, thus enabling multiple parallel transmissions to take place.

We then consider a variation of this network scenario where the number of available data channels is equal to 2; the corresponding numerical results are shown in Table 3. In this case, MC-POWMAC protocols achieve the maximum performance. Obviously, the same behavior is observed if the data channel ND>2, since only two connections are active in this scenario.

Node scenario: We then consider the network scenario illustrated in Fig. 5, where 4 connections are active: C1 between nodes 1 and 2, C2 between nodes 3 and 4, C3 between nodes 5 and 6 and finally C4 between nodes 7 and 8.

In this scenario, only MC-POWMAC allows connections C1 and C2 to transmit at the same time as C3 and C4 on the same data channel, since it performs power control and multichannel presence. This is reflected in the higher throughput values and the number of served users obtained by MP-POWMAC which is appears in figure a good balance between these two performance figures, since it delivers a consistently high level of fairness regardless of network topology and traffic type, maintaining at the same time high good put.

Figure 6 demonstrates the signal to interference noise ratio at the first node in the previous scenario, this figure illustrate that the value of SINR change in random manners since its depend on the value of the gains (either from the intended signals and from the unintended signals) which is taken along this simulation as a random value. Also SINR represents one of the two major conditions to execute the transmission (SINR>SINRth and Ppowmac>Pmin).

Table 4 illustrates the rate of served user in the last scenario. The upper table illustrate that the serving rate decrease as the signal to interference noise ratio threshold increase since its affects the double conditions which needed to perform the concurrent transmission. Also we conclude from the table that the amount of transmission power doesn't affect the value of the serving rate.

Table 5 illustrates that the throughput rate decrease as the SINRth increase since its affects the double conditions which needed to perform the concurrent transmission. Also we conclude from the table that the amount of transmission power doesn't affect the value of the serving rate.

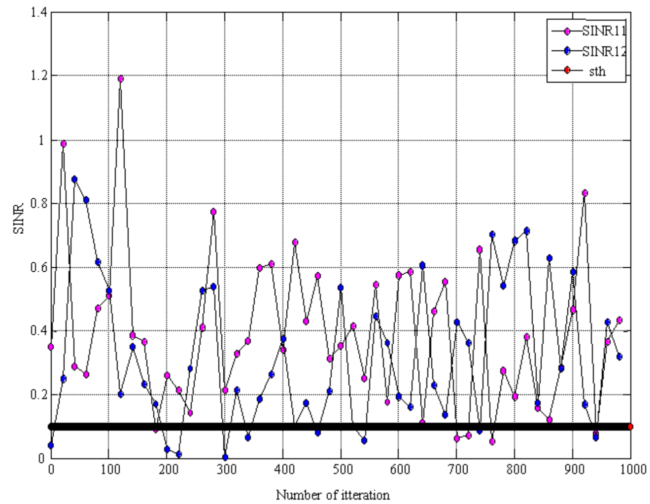

Fig. 6: SINR on the first node pair of the 8-nodes scenario

Table 4: Serving rate versus SINRth

SINRth	Served rate versus transmission power 100 mW	200 mW	300 mW	400 mW
0.1	0.7462	0.7475	0.73875	0.73825
0.2	0.5065	0.5075	0.5085	0.49725
0.3	0.2980	0.3095	0.308	0.31825
0.4	0.1550	0.15475	0.13875	0.15
0.5	0.05950	0.05925	0.055	0.06325
0.6	0.02650	0.02275	0.027	0.02575
0.7	0.00825	0.01125	0.01175	0.01125
0.8	0.00200	0.005	0.0055	0.00175
0.9	0.00250	0.00225	0.00225	0.00175
1.0	0.00125	0.0025	0.00225	0.001

Table 5: Throughput rate versus SINRth

SINRth	Throughput rate versus transmission power 100 mW	200 mW	300 mW	400 mW
0.1	0.7385	0.7468	0.742	0.721
0.2	0.515	0.5102	0.5118	0.4965
0.3	0.313	0.319	0.3085	0.3187
0.4	0.1440	0.153	0.1345	0.14
0.5	0.0615	0.0595	0.0638	0.0635
0.6	0.0088	0.0227	0.0293	0.0217
0.7	0.0095	0.012	0.0115	0.01
0.8	0.0053	0.0065	0.0037	0.0055
0.9	0.0027	0.0032	0.005	0.0022
1.0	7.5×10^{-4}	1×10^{-3}	0.0013	1×10^{-3}

CONCLUSION

In this project, we proposed a power controlled MAC protocol for MANETs, known as MC-POWMAC. Similar to the POWMAC scheme, MC-POWMAC is based on a single-transceiver circuitry and it operates over a multi-channel for data and control packets. MC-POWMAC adjusts the transmission powers of data packets to allow for some interference margin at the receiver. Multiple interference-limited transmissions in the vicinity of a receiver are allowed to overlap in time, provided that their MAI effects do not lead to collisions at nearby receivers.

We compared the performance of MC-POWMAC with that of single channel POWMAC scheme. The simulation results showed that MC-POWMAC can improve the network throughput by up to 74% (it was about 50% in single channel POWMAC) referring to 802.11 scheme and I hope much more than that in clustered topologies. However, throughput and energy consumption for MC-POWMAC were less than those of MIMO-POWMAC. This behavior is attributed to the reduction in the number of concurrent transmissions when the MIMO mode is used. These results applied for eight node scenario over two data channels. Furthermore, MC-POWMAC can achieve some reduction in the energy consumed to successfully deliver a packet from the source to the destination.

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