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School of Computer Science
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# A Survey on "Integrated Channel-assignment and Power-control in Wireless Ad Hoc Networks"

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# Abstract

*The goal of this paper is to investigate and present a comprehensive survey and review some important issues of research activities concerning wireless ad hoc networks. This literature survey analyzes relevant topics of different researchers towards channel-assignment & power-control and their individual effect on network capacity and the throughput. As well, how the integration of channel-assignment and power-control could further enhance the present-day high-demand communication features in respect to network capacity and throughput is covered. Since wireless is the only medium that achieves the goal of our dream to be able to communicate to anyone, anywhere, anytime.*

# 1 Introduction

## *1.1 Wireless Networks*

The worldwide communication and network structure has experienced a rapid change due to the tremendous demand and growth of the internet with availability of various network applications as well as the availability of cheaper hardware [101]. In this context, the wireless network is the best technique in the era of multimedia communication especially for mobility and location-independent communication.

Wireless networks are becoming more popular since the last decade because of their hardware improvements including availability, portability, low-power, ease of access to telephone and data networks [56] caused by the quick exploitation of network infrastructure.

## *1.2 Types of Wireless Networks*

Wireless networks may be classified as follows:

### 1.2.1 Infrastructure-based networks or Cellular Networks

In the past decade, wireless cellular networks have experienced an explosive growth due to the advancement of cellular technologies. To fulfill this upward trend cellular networks are becoming more diverse in service, better market price, and better performance in service. In a cellular network, a service area is divided into some sub-areas called cells and each cell is served by a more powerful entity called the base station which is connected to a network infrastructure. Although a base station is fixed but it is responsible for coordinating communication between one or more nodes within its coverage area. This network is more suitable for the geographical area where nodes are spread uniformly and infrastructure exists or availability of infrastructure is possible easily. As this survey is mainly concentrated on wireless ad hoc networks, cellular networks will not be further discussed.

### 1.2.2 Wireless Ad Hoc Networks

Nowadays, one of the most prospective communication fields is the ad hoc network due to the increase of inexpensive, available devices and the network community's intense interest in mobile computing. An ad hoc network is an autonomous system consisting of a collection of distributed hosts that communicate to each other by forming a temporary network dynamically without any support of wire or administration [25]. An ad hoc network mainly differs from a regular cellular network in that it can be formed without use of any existing network infrastructure or centrally-controlled administration. An ad hoc network might not directly communicate with another node if that is not the adjacent one. Unlike regular cellular networks, there is no master-slave relationship i.e. no central-station to user-nodes relationship exists in Ad-Hoc networks.

[5] explains that the absence of infrastructure in a network means the nodes communicate with each other directly or in a peer-to-peer fashion. A key assumption is that all the nodes cannot communicate directly with all other nodes, so the neighborhood nodes are required to relay packets in favor of other nodes in order to deliver data access networks. In ad hoc networks the nodes are mobile and sizes are small. Therefore these nodes introduce limitations to the power capacity as well as the transmission range. It is necessary for each node to be able to work as a router as well. Again, the nodes of ad hoc networks have limited bandwidth which introduces channel-assignment constraints so that collisions of packets and call droppings can be reduced significantly.

The main goal of wireless ad hoc networks is to allow a group of communication nodes to set up and maintain a network among themselves, without the support of a base station or a central controller. From the application perspective, ad hoc networks are suitable for areas where infrastructure is not available, not trustworthy, very costly, or cannot be relied on times of emergency. Some of the examples are: disaster relief, earthquake, battle field, space exploration, the forestry, rare animal tracking, under ocean/sea operations, conference meeting, personal networking, and PDA systems etc. Ad hoc networks could empowe medical personnel or civil servants to better coordinate their efforts at the large-

scale emergency situation that breaks the existing infrastructures, such as September 11 attacks and 2003 blackout in the north east region of USA.

### 1.2.3 Sensor & Personal Area Networks

Wireless sensor networks consist of a number of inexpensive small-scale nodes that are organized for data collection from a network field. These nodes are capable of limited computation, wireless communication and sensing among themselves in a wireless sensor network. Sensor networks are suitable for some specific applications, like geographical monitoring, agriculture, military systems, habitant monitoring, transportation, business process etc.

On the other hand, a personal area network (PAN) consists of devices within 10 meters of a person or system depending the PAN's hardware. This means that a PAN is suitable for covering an entire house, a set of offices but not suitable for an entire building. Again, a detailed discussion of sensor networks and personal area networks is not in the scope of this survey.

## *1.3 Structure of the Survey*

This survey covers channel-assignment, power control, and the integration of channel-assignment and power-control in wireless ad hoc networks. This survey consists of six sections; section-1 discusses the general introduction of wireless networks including Cellular networks, Ad hoc networks, sensor networks, and personal networks. Other parts of the survey are organized as follows.

In section-2, a general overview about channel-assignments, power-control techniques and the related difficulties they face is discussed, with a clear outlining of how they influence the wireless ad hoc networks. As well, the integration of Channel-assignment and Power-control with their combining effect on ad hoc networks over their individual effect is discussed.

Section 3 describes the approaches used for design and implementation of channel-assignment in wireless ad hoc networks.
Section 4 discusses the power-control mechanisms available in the environment of ad hoc networks. It emphasizes the protocols and algorithms that appear in the literature of power-control in ad hoc networks.

In section 5, approaches to integrate channel-assignment and power-control are discussed in detail. As well as their ultimate affect on the network capacity and throughput in wireless networks is discussed.

Finally, in section 6, the main conclusion is presented, as well as possible directions for future work that are still open.

The appendixes which contain Bibliography, Annotated bibliography, leading researchers list, Cross reference graph, and communication with researchers, are given at the end of the survey.

# 2 Basic Issues

The basic issues related to channel-assignment and power-control are very important and require special attention during the design and implementation of different type of channel-assignment protocol and power-control methodology in wireless ad hoc networks. The regular and important issues that were considered by most of the researchers are as follows:

## *2.1 Channel Management*

Channel management is simply a proper management of the frequencies in the development of a better inter-communication plan in presently-available highly crowded electromagnetic bandwidth. If proper steps are not taken during the planning stage, the frequency selection might create interference among nodes which in turn decrease the network capacity and throughput. In ad hoc networks direct channel management is not a requirement so we will not discuss it in detail.

## *2.2 Channel-assignment*

In [7], [24], [34], [43], [50], [51], [60], [105] channel-assignment is described as a process that assigns calls to the channels of wireless ad hoc networks. It is a fundamental task of resource management that increases the fidelity, capacity, throughput, and quality of service in ad hoc networks in such a way that efficient frequency utilization is possible as well as the elimination of frequency interferences.

Channel-assignment is classified into three groups; fixed channel-assignment (FCA), dynamic channel-assignment (DCA), and hybrid channel-assignment (HCA). In FCA, channels are allocated to the nodes in advance on the basis of estimated load traffic. On the other hand, in DCA, the channels are assigned randomly as calls arrive in networks. DCA makes wireless networks more efficient especially if the traffic load distribution is not known or varies with time. Also, there is a drawback in DCA which requires more composite control and is generally time consuming.

Hybrid channel-assignment is nothing but the combination of FCA and DCA, in which a set of channels is divided into two subsets; one uses FCA and the other uses DCA.

### *2.3 Media Access Control (MAC) Protocol*

The rapid growth of wireless communication put a tremendous pressure on the communication regulatory agencies so that the free RF spectrum will be possible to satisfy the exponentially growing bandwidth demand. The MAC protocol is the one that fulfills the above requirement by defining and controlling access to the wireless channels.

In [21], the MAC protocol simply determines when a node should transmit data packets as well as controlling all types of access to the physical layer in the wireless network. There are a number of well-known MAC protocols that are widely used, such as; Frequency Division Multiple Access (FDMA), Time Division Multiple Access (TDMA), Code Division Multiple Access (CDMA), ALOHA protocols, and Carrier Sense Multiple Access (CSMA) protocols.

### *2.4 Interference*

The transmission carried over between nodes in a wireless ad hoc network interferes with neighboring links, significantly reducing the capacity of the networks. Interference occurs in one node due to the transmission of other third party nodes on the same channel [27]. One can define interference as the amount of noise power that is not intended to a node but still it is sensing due to the communication between other nodes [25]. Usually the interfering transmitter is distant, and in theory its signals should not arrive at the receiving site. Unfortunately coverage areas by transmitting nodes cannot be exactly defined. If the interference level in a network largely increased then the call between caller and callee could be blocked as well as could be dropped, because in this situation the signal-to-interference ratio (SINR) falls below the minimum SINR. In [32] and [33], careful consideration has been taken for the transmission in such a way that a least interference channel (LIC) is selected by measuring the interference level at all the outbound links, provided the interference level is below the interference threshold.

### *2.5 SIR or SINR*

The SIR or SINR is a measuring unit of received signal at a receiver in an ad hoc network. In [33], the ratio of the wanted signal to the unwanted remaining power at a receiver is called signal-to-interference ratio (SIR) or signal-to-interference-and-noise ratio (SINR). Usually a threshold value of SIR is determined to deduce the correctness of the wanted signal at a receiver. Lower SIR at a receiver indicates the higher error rate and low utility in a network. But higher SIR value indicates the higher throughput and high utility in a network. If the SINR value falls below the MINSINR at any receiver then the calls might be blocked or dropped depending on the situation.

### *2.6 Power Control*

The power-control is the procedure of determining the transmitted power of each communication node in an ad hoc network. In [5], the author says that the efficient management of power-control may be beneficiary for us in wireless ad hoc networks, because of its influence on the battery life of the communication devices and on the capacity of the networks. Thus the energy savings and the efficient use of network resources are the two components that make power-management one of the most challenging topics for the researchers in wireless communication.

[87] unlike in cellular networks, most of the mobile hosts in ad hoc networks operate using batteries, so it is important to minimize the power consumption of the entire network. Minimizing the power consumption ultimately maximizes the life-time of the ad hoc networks. If the transmitted power is very high then the battery will be drained off quickly which in turn reduces the battery life tremendously. At the same time the decay of battery life also affects network lifetime in ad-hoc networks.

The above discussion helps to motivate the researchers that the adjustment of transmitted power is extremely important due to the following reasons:

- The transmitted power of a node determines the network topology.
- The communication terminals in ad hoc networks are usually energy constrained.

- Transmitting high power could degrade other communication systems or networks.
- Transmitting of higher power is unnecessary if the receiver is close to the transmitter.

### *2.7 Integrated Channel-assignment and Power Control*

Channel-assignment and power-control are two effective means to improve the capacity of wireless networks [2], [4], [11], [14], [17], [44], [57], [65], [88], [102], [105], [106]. By integrating these two, one can further increase the network capacity and throughput [20], [33], [44], [61]. That is the main focus of this survey which is mainly concentrated on the integration of channel-assignment and power-control that is how power-control could be collaborated with channel-assignment to maximize the network capacity and network throughput.

# 3 Approaches to Channel Assignment

In order to assign channels properly and efficiently in wireless ad hoc networks different researchers have used different channel-assignment schemes. The researchers are highly motivated about the reuse of channel-assignment, efficient frequency utilization, as well as the frequency interferences can be eliminated. Different model names can be assigned to the different channel-assignment techniques that are as follows:

## *3.1 The Dynamic Channel Allocation (DCA) Model*

All of the methods in [9], [7], [36] that follow this model perform dynamic channel-assignment which assigns channels using an on-demand basis in a network. These approaches do not take into consideration about the power savings or power controls in their analysis.

The Authors of [9] said that their DCA is the first MAC protocol where channel allocation is done based on the feedback of contention information occurs at the receiver. In [34], [11], [56], channel assignment is done through Fixed Channel Allocation (FCA) using MACAW, DBTMA, FAMA protocols where network throughput is very poor due to the collisions of data-packets because of hidden and exposed nodes. DCA in [9] provides higher normalized throughput by using the combination of RTS-CTS messaging, a query packet, and a busy tone as well as the contention information of the receiver which in turn avoids the collisions of data packets.

On the other hand, although the same technique is used in the DCA scheme in [7] but here channel allocation is mainly done with the detection of interference at the receiver which ensures the perfect reception data-packets under ideal conditions. So DCA [7] introduces a collision-free MAC protocol with higher throughput than the existing corresponding techniques.

The DCA methods have better performance for light traffic load, because they can balance the traffic load better. Under a heavy traffic load, the wireless ad hoc network is near its full capacity; even DCA is not capable of avoiding high call reject rates.

The problems which arise in DCA methods above under heavy traffic load could be reduced by a hybrid method introduced in [36]. Since the hybrid channel allocation method is a mixture of fixed and dynamic channel allocation, it performs well as a fixed channel allocation method under light traffic. Also this technique gives better performance, especially under heavy traffic loads, because they can balance the traffic load better. Under the hybrid method, when traffic load increases, the percentage of blocking channel rate increases more slowly than for the traditional methods.

This type of model is being used and supported by the Multidisciplinary University Research Institute (MURI) under the Office of Naval Research Contract N00014-00-1-0564.

### *3.2 The Two-Way Handshaking Model*

The major concern of this model is to assign channels dynamically by exchanging few messages between transmitter and receiver without any clock synchronization. All of the approaches [7], [43], [101], that follow the RTS-CTS two-way handshaking method carry out dynamic channel-assignment in ad hoc networks in an on-demand manner. Some methods extend RTS-CTS two-way handshaking method to four-way handshaking features.

The authors in [101], introduce a simple multi-channel MAC protocol, called SM based on the mechanism of two-way handshaking (RTS/CTS) reservation. Unlike [9], [7], [36], the SM protocol does not need any form of clock synchronization among mobile hosts. Both the channel assignment and medium-access problems are solved in an integrated manner. But this approach includes two problems; firstly what happens if two transmissions are started at the same time; secondly what happens if there is a hidden or exposed node? There will be plenty of call blocking and call dropping due to the hidden or exposed nodes.

In [91], a MAC protocol called DCA-PC (dynamic channel-assignment with power control) is being used which is an extension of the earlier DCA protocol in [7], [9], which do not take power-control into consideration. Here network capacity and channel utilization is better than before [7], [9].

To improve the network capacity of [91] further a Multi-Channel MAC (MMAC) protocol is proposed in [92]. As the IEEE 802.11 standard protocol offer multiple channels for use but its MAC protocol is designed only for a single channel, thus the MMAC protocol is an improvement over single channel MAC protocol as well as over the existing multi-channel MAC protocol discussed in [7], [9], [91].

The problems arise in [101], are overcome by a novel concept called Distributed Call Reservation Scheme (DVRS) introduced in [43]. As in DVRS, the sender sends a small packet called as RTS before data transmission which carries the destination address and the length of data. Even though in DVRS, two nodes send this packet at same time then only these small packets are destroyed i.e. no call blocking or call dropping arises. Thus the typical hidden-node problem is resolved but still there might be collisions due to the "deaf-node" situation as in figure 1.

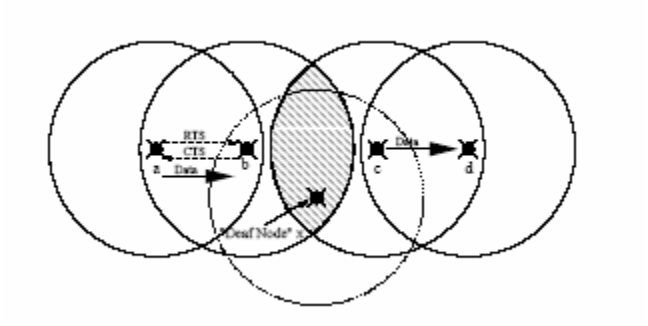


***Figure 1: Deaf Node Situation (Ref. [43], Page: 1)***

The authors in [43] introduce another novel scheme called the Distributed Cell Reservation Scheme (DCRS) which solves the deaf-node problem.

DCRS defines a frame which consists of fixed number of cells as in figure 2 and then applies the following rules:

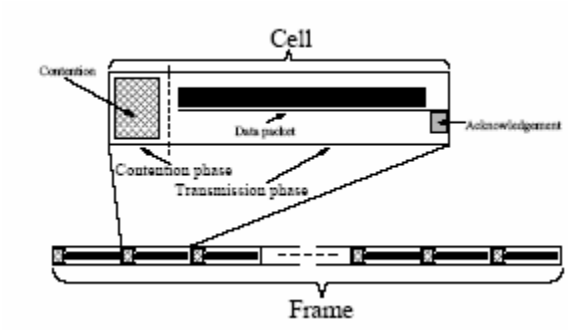


***Figure 2: Frame Structure (Ref.- [43], Page: 2 )***

- A high-priority cell is only allowed to send if this particular cell is reserved in the previous frame or it is allowed to send in the previous frame.
- By sending a medium cell the above mentioned high-priority cell could be reserved provided it has to win the contention.
- To transfer best effort cells one may try it in any cells using low priority.

Some of the ad hoc networks researchers prefer to use this model not only because it is independent of clock synchronization among all mobile hosts, which is difficult when the network is isolated in a large area. Also the protocol used under this model is degree independent and using this protocol will experience less degradation when the network is highly crowded.

### *3.3 The Interference-based Model*

Under this model, all methods [7], [14], [65] assign channels on the basis of interference type at the receiver. A simple aggressive algorithm known as the Least Interference Algorithm (LIA) is presented in [14]. In LIA the instantaneous power measurement is used to select the channel with the least-received interference power. The selection of the least received interference channel minimizes overall interference power in the system and thus increases the network capacity.

The authors of [7] claim that the DCA is the first MAC protocol that assigns channels on the basis of interference type at the receiver. They claim that the detection of interference at the receiver ensures the perfect reception of data-packets under ideal conditions.

While most of the existing algorithms for the channel-assignment problem are based on single interference, only the minimum-span frequency-assignment protocol (MS-FAP) in [65] takes into consideration multiple interference with minimize the span. The algorithm presented in [65] is based on a nondeterministic tree search (ANTS) algorithm, which is a metaheuristic algorithm based on a computational paradigm inspired by the way real ant colonies function. This approach tries to find an interference-free assignment using as few frequencies as possible to the transmitters that minimize the span. Also this approach is very promising and it outperforms existing algorithms with all benchmarks except with large-dimension problems.

Another interference-based channel-assignment strategy is well discussed in [105], where some of the channel-assignment schemes have been studied to improve the performance of Dynamic Channel Allocation (DCA) schemes. These interference-based schemes are Random Channel Selection (RCS), Sensing-based Channel Selection (SCS), and Probing-based Channel Selection (PCS) schemes. The shortcomings in RCS and SCS schemes is that, here the interference could increase dramatically and force some transmissions to be dropped. On the other hand, in the PCS scheme the interference caused to other link's transmission power is reduced significantly.

With the SCS channel-probing scheme, it is possible to perform predictive/interactive admission control of channels. Intuitively, it was claimed that the performance of the SCS scheme is best in all respects, because SCS provides a way to better protect active users as well as to make better channel selection for new users. Although all of the above channel probing schemes are more complicated than traditional schemes and requires more overhead, but they have the potential to achieve higher network capacity.

### *3.4 Channel-Probing Schemes*

The channel probing schemes introduced in [105], under the interference-based model are based on the assumption that the set of active links is used to update their transmission power frequently, which in turn increases the interference in the channel quickly. But these active links experience additional interferences when a set of new links joins the channel and start to transmit.

In [106], the above-mentioned problems are overcome by introducing a distributed channel-probing scheme called Probing Channel Selection (PCS), which can be used as a part of the dynamic channel allocation scheme. The PCS scheme allows the transmitter and receiver to probe a channel that estimates the channel condition or channel admissibility and meets the target signal-to-interference ratio (SIR). Thus a best channel could be chosen for a given link by executing the probing scheme algorithm in that link. The authors claim that the newly-arrived calls face less blocking experience and fewer disruptions in this scheme. They also claim that in PCS, the interference caused to other links is reduced significantly, because here the link is blocked without further trying to power-up in any of the channels if all the channels are inadmissible.

### *3.5 The Disk Graph Model*

The approach of the algorithms under this class is based on the concept that the direct collision and hidden-terminal interference in the network could be eliminating by introducing a variety of disk graphs model. From the other existing research it is shown that in Unit Disc (UD) graph, Intersection Disc (ID) graph, and Containment Disc (CD) graph, a node is represented as a single disc. The UD model is not realistic but it set a foundation for other classes of disc graph.

In the ID graph model, two nodes are considered to be interfering if their discs intersect; and in the CD graph model, two nodes are considered interfering if at least one disk contains the center of another disc. It is shown that the CD graph accurately represents the direct collision but not the hidden terminal collision. On the other hand, the ID graph represents both types of collision but it is so conservative. Another generalized class of disc graph came into the discussion is Direct Disc (DD) graph, where two nodes are considered interfering if one node's interfering area intersects with another node's supply area. DD graph model more accurately represents the real network than the ID and CD models. However, DD has the same limitation as ID, i.e., it does not consider the existence of nodes in the overlapped area.

The authors in [15], introduce a new class of disk graph called the interFerence Disk (FD) graph model, in which a heuristic algorithm is designed for graph coloring approach to avoid confusion with ID and DD by minimizing the interference. This model is built on the DD model but more accurately represents reality. The authors claim that the FD graph model requires less number of channels than intersection Disk (ID) and Double Disk (DD) graph models but requires more channels than Containment Disk (CD) graph models. It is claimed that the interFerence Disk (FD) graph represents the real network more accurately than CD, ID, and DD graphs.

### *3.6 The Assignment & Reassignment Model*

This model considers the limitation of available channel or bandwidth resources where only the reuse of channels can promote the utilization of channels as well as it can enhance the network capacity. In [11], a channel-assignment and re-assignment protocol was proposed which prevents the co-channel interference when one pair of communicating hosts becoming closer to another pair of hosts using the same channel. It was claimed experimentally that channel-assignment and reassignment increases the network capacity as well as decreasing the rate of call dropping among hosts in ad hoc networks.

### *3.7 Modulation-based models*

The approaches [50], [51] under this model use the Frequency Division Multiple Access (FDMA) protocol. In [51], the important issues considered are the fading characteristics and interference due to the reuse of frequency. A heuristic algorithm is presented based on minimum increment power in each step which out performs the entire least interference-based algorithm [7], [14], [43] that has been used previously for channel allocation. This heuristic algorithm results in an efficient assignment of frequencies and transmitter power levels in terms of the energy required for transmitting each bit of information.

The authors in [50] introduced an Orthogonal Frequency Division Multiplexing (OFDM) modulator to present a distributed algorithm for sub-carrier allocation. This algorithm makes possible the simultaneous transmission for each point-to-point link by using a subset of the available bandwidth. This multi-carrier modulation technique has reduced the inter-symbol interference and multi-path delay spread considerably, thus making transmission possible of high symbol rates.

### *3.8 Summary of Approaches to Channel Assignment*

As the nodes in Wireless Ad-Hoc Networks communicate with one another over scarce wireless channels in a multi-hop fashion, therefore appropriate and efficient channel assignment is a very challenging and critical research issue. The models 3.1, 3.2, 3.3, 3.4, 3.5, 3.6, and 3.7 present some strategies for channel assignment which increase the reuse of available frequencies and thus enhance the network capacity. The model 3.1 mainly deals with MAC-layer protocol, in particular the family of Carrier Sense Multiple Access (CSMA) where the proper bandwidth utilization is limited by the two interference mechanisms i.e., the hidden terminal and exposed terminal problems. In general, the hidden terminal problem reduces the network capacity due to increasing the number of collisions, while the exposed terminal problem reduces the capacity due to the unnecessarily suspending nodes from transmitting.

Several attempts have been taken in the literature to reduce the poor effect of these two problems. In the model 3.2, a dialogue between transmitting and receiving nodes is being used that anticipates the actual transmission, referred to as RTS/CTS dialogue which reduces the chances of collisions. Although RTS/CTS dialogue does not fully eliminate the hidden and exposed terminal problems, it provides some degree of improvement over the traditional CSMA schemes. The approaches used in the models 3.3 and 3.4 mainly focus on the amount of interference level and signal-to-interference level between the transmitter and the receiver. In these approaches, basically least interference channels (LIC) are selected by measuring the interference level of all the outbound links.

Another model in 3.5, present some algorithms based on the notion that the direct collision and hidden-terminal interference in the network could be eliminating by introducing a variety of disk graphs model. On the other hand, the modulation model in 3.7 is becoming an increasingly popular technique and has been standardized for Digital Audio Broadcast (DAB) and Digital Video Broadcast (DVB). OFDM technique was adopted in the new 801.11a standard in the Wireless Local Area Networks. Also Cisco is considering vectored OFDM for digital microwave communications.

# 4 Approaches to Power Control

As in [90], using power-control may bring several advantages such as longer battery life time, may reduce co-channel interference among neighboring hosts, and it may enhance channel reuse. In order to increase the network capacity, efficient management of power-control is very important in wireless ad hoc networks, because of its impact on the battery life of wireless devices and on the capacity of the networks [5]. Thus the energy savings and the efficient use of network resources make power-management one of the most interesting areas for researchers. For efficient power-control in ad hoc networks different researchers have used different power-control schemes [12], [23], [24], [40], [57], [58], [63], [87], [98].

## *4.1 The MAC Protocol Model*

All of the methods [23], [24], [58], [37], [47], [38], [102] that follow this model perform power savings under the MAC protocol and thus increase the network capacity. Among these approaches, different researchers use different schemes. For example [38], [58], [102] use two-way handshaking (RTS-CTS) algorithms with their corresponding MAC scheme. Other approaches use different schemes under the MAC protocol.

In [58], a judicious power-control MAC protocol called PCMAC is used to enhance the original MAC protocol in the IEEE 802.11 standard by improving the handshaking mechanism and adding one more separate power control channel. With control channel, the receiver notifies its neighbors about the noise tolerance, thus the neighbors can adjust their transmission power levels to avoid packet collision at the receiver. This PCMAC power control allows more simultaneous transmission with manageable interference and the battery power will be saved by minimizing the asymmetrical link problem arising in all other existing power-control schemes. PCMAC can be incorporated in the existing IEEE 802.11 standard, making it practicable in a real environment.

Similar work, reported in [23], mainly focuses on battery-power savings which will ultimately enhance the network capacity and throughput. In [24], it is observed that there is a tradeoff relationship between RF transmission power and the packet retransmission. But reduction of transmission power may cause a packet error, thus resulting in excessive retransmission, which is very power does not consuming. It means reducing of transmission power not necessarily save the battery life. In [72], the author suggests a scheme that can considerably save power by adjusting the transmission power. A similar idea is reported in [98] where network topology is dynamically controlled by transmission power, thus the battery-power is saving dramatically. Which in turn increases the network capacity and the network throughput?

Two other articles, [37] and [47], followed a slightly different concept. In [37], an energy-efficient MAC algorithm based on reservation and scheduling is proposed which protects mobile terminals from collision and retransmission under heavy traffic load. Thus increasing the power consumption savings and hence increasing the throughput.

On the other hand, for light network traffic, another MAC protocol DPC/ALP came into the scenario [47], which can deliver an extremely short session without excessive delay in the power-up phase. An access-control scheme called adaptive probing has been developed which is capable of deciding the maximum allowable data rate. Unlike other CSMA schemes, DPC/ALP does not wait for other mobiles to end their transmission; instead it can selectively transmit at lower data rates in the presence of multiple active transmissions. As a result, it can lower the transmission delay even in heavily loaded networks, and performs better than standard approaches. It is claimed by the author that this protocol can save power more than 20 dB in light network traffic, and the delay is smaller than a quarter of that High Rate IEEE 802.11b (11 Mbps) in heavy network loading, while using the same or less power.

In [38], a power-control MAC protocol referred to as the BASIC scheme, based on the RTS-CTS handshaking protocol is proposed. Under this scheme the RTS-CTS are transmitted using the highest power level and DATA-ACK is transmitted using minimum power levels in order to save energy or battery life considerably. However, this BASIC scheme increases collisions and retransmissions, which can result in more energy consumption, and throughput degradation. To overcome these difficulties, the authors proposed another Power Control MAC protocol, PCM, which periodically increases the transmit power during data transmission. PCM protocol achieves energy savings without causing throughput degradation where the status of interference level was not considered at all.

Following [38], a similar report is presented in [102], which combines the intelligence of power control, RTS-CTS dialogue, and busy tones to increase the power savings as well as the channel utilization. Under this environment a sender used relatively low power level so that the channel reuse can be increased. Thus, together with the extra benefit such as saving battery energy and reducing channel interference shows a hopeful path to enhance the performance of Mobile Ad Hoc Networks.

### *4.2 The Transmit Power Level Model*

All the methods [1], [6], [17], [27], [40], [59], [73] that follow this model accomplish power-control in ad hoc networks by controlling the transmission power, i.e., either keeping the transmit power fixed or adjustable.

In [1], a power-control loop algorithm is used to allow all nodes to communicate with their neighbors by choosing different transmit power levels for each of them. Thus interference is reduced and energy consumption is increased by 10-20%, and the overall throughput is increased by 15%. Another similar analysis [17], presents two power-control schemes that balance the tradeoff between link maintenance and power consumption. The authors consider that increasing the transmit power for a user makes the outgoing links more reliable. On the other hand, the increase of transmit power may decreases the battery life which might causes interference to other users.

The authors in [6], have introduced a power control algorithm in the single channel case and multi-channel cases. New request probes several channels for the fastest and feasible admission to the network based on the number of iteration to reach required SINR. Another observation has been made in [27], a first power-management scheme is introduced that is being with traditional routing protocols without any major modification to the protocols themselves. The shortcomings of [17] are overcome by [27] where a node communicates by adjusting the power as needed to communicate with all the nodes. But this scheme still has lack of information about power levels when nodes are non-homogeneously or clustery spread over the network space.

In [40], three power controls: CLUSTERPOW, Tunneled CLUSTERPOW and MINPOW algorithms are proposed to enhance the drawback of [27]. Here a power level is chosen so that all the intra-cluster communication is possible with a lower transmit power level and all the inter-cluster (different cluster) communication use a higher transmit power level. [59] addresses a topology control problem based on different optimization objectives like minimizing maximum power and minimizing the total power.

Power savings in [73] are achieved through two centralized algorithms in two constraints such as connectivity and bi-connectivity, and one objective of maximum-power optimality. Here two distributed heuristic algorithms adaptively adjust the transmit power of each node which ultimately reduces the power consumption.

### *4.3 The Local Information Model*

This model is followed by the approaches described in [25], [82], [87], [96], [97], [98], where power savings carried out by the local information of the next hop in a network. Such as in [25], the next-neighbor transmissions are focused where transmitters send packets to their respective receiver on the basis of SINR. It limits the multi-user interference to increase single-hop throughput and reduce power-control to increase the battery life.

The authors of [82] propose a four-step algorithm that coordinates transmissions where every node has a single directional antenna. At first it performs energy-efficient routing to find the minimum-energy path and then creates a schedule of node transmissions. It is argued that this algorithm achieves all the possible gain in transmitter-receiver communication and that another 45% improvement in network lifetime is achieved by energy-aware routing.

In [87], Toh et al. suggests that each host in a network has to locally select the next host, having only the idea of the remaining battery capacity of the neighbor nodes such that capacity does not fall in its transmit coverage range. There are two power-control schemes addressed in [96], a distributed power-control scheme and a distributed joint-scheduling and power-control algorithm. The first scheme provides an optimal solution that minimizes the power consumption incorporation with the desired SINR at the receivers and the second algorithm solves some of the specified power-control problem by eliminating the comparatively strong interferences.

A similar report is presented in [97] where only the local information is required to construct and maintain a logical topology on the unit disk graph. A distributed algorithm first constructs a Gabriel graph from the available unit disk graph and then the aggregate power is reduced by replacing the critical links by replaceable paths.

In [98], each node in a multi-hop wireless ad hoc network takes local decisions by itself about the transmit power which collectively strives towards global connectivity. Here a node gets the directional information of its closer neighbor nodes in all directions and increases it's transmit power until a node is discovered.

### *4.4 The PARO based model*

The PARO [30] based model is a power-aware routing optimization technique, that helps to minimize the transmit power required for wireless networks. Here the intermediate nodes redirect to forward packets or data between source-destination pairs which reduces the overall transmission power, thus increasing the overall lifetime of the network devices. In fact PARO adds only the additional redirector nodes to maximize the number between source-destination pairs. Thus this approach leads the nodes to be dynamically capable of adjusting their transmission power on a per-packet basis.

### *4.5 The Wakeup- Sleep model*

All of the approaches [12], [18], that follow this model significantly save energy consumption without a significant compromise of network capacity and connectivity. In [12], a power-saving technique named span is used where each node takes the decision whether it will go to sleep or wake up to help as a coordinator for communication between two of its neighbors. The authors demonstrate that the system lifetime with span is more than twice than that without the span.

In [18], a distributed power-management scheme is proposed where a power device could be activated remotely by any sort of waking-up signal using a simple RF tag technology. In that way a node may enter a sleep state if it is not currently used and will wake up when traffic is to bet transmitted by this node. Also a node can select a sleep pattern according its QOS and battery status, as well as it can enter a sleep state only if they are idle. At heavy traffic load a 24% of power gain is possible to obtain in this scheme.

### *4.6 Summary of Approaches to Power Control*

All the models 4.1, 4.2, 4.3, 4.4, and 4.5 presented above have the tremendous interest to reduce energy consumption because reduction of transmission power results in smaller number of nodes overhearing the transmission. Thus, all the power control approaches provide more or less the following functionality:

i. Lowest possible power to be used for the communication.
ii. Ensure network connectivity.
iii. Guaranteed power MAC functionality.
iv. Introducing little overhead.

In summary, the MAC protocol model described in 4.1 sends the RTS and CTS packets with the maximum possible transmit power level, while it sends the DATA and ACK packet using minimum necessary power level. Unfortunately, this model may increase the possibility of collisions. More collisions means more retransmissions and a lot of energy are wasted because of retransmission as well as collisions also degrade the throughput.

Whereas the transmit power level model in 4.2 sends RTS and CTS packets with maximum power level and DATA packets are sent with minimum necessary power level but will be increased to the maximum level periodically. Thus, the collisions arise by the model 4.1 are avoided in 4.2. On the other hand this model requires frequent increase and decrease in the transmit power which may make the implementation difficult.

The models in 4.3, 4.4, and 4.3 use different channels for data and control. Under these models, 50% lesser energy consumption is achieved and performance could be reaching 2.4 times greater than that of the 802.11 based MAC.

# 5 Approaches to Integrate Channel-assignment and Power Control

In most ad hoc networks, performance depends heavily on the power consumption associated with the transmission of signals. The efficient use of power in each node can enhance the life time of the whole network and reduce the interference in different links. Various studies have been done in several papers regarding channel assignment algorithms. Also power-control algorithms have been studied in several papers. Together with power control, optimal channel allocation can maximize the utilization of channels.

Also in ad hoc networks there is usually more than one non-interfering channel available. So proper channel allocation and power control should be considered at the same time. The above discussions suggested to researchers that in order to increase the network capacity significantly, it is needed to integrate the channel-assignment and power-control together [14], [20], [33], [44], [61], [81]. By integrating these two, one can further increase the network capacity and throughput. Though in this survey channel-assignment and power-control are thoroughly discussed individually but our ultimate goal is to investigate how one can maximize the network capacity and throughput by incorporating power-control with channel-assignment. Since there were not more research on this integration technology before, so a few of the research papers which includes this integration technology are presented here. All the methods use Dynamic Channel Allocation (DCA) with the incorporation of power-control is discussed here.

In [20], an autonomous algorithm is presented to combine the dynamic channel-assignment (DCA) and power control. Here the DCA algorithm is based on the determination of paired channels that have very-low level of interference or have very-low possibility of causing interference. The power-control algorithm uses local estimations of signal-to-interference-ratio (SINR) at a receiver which leads to adjustment of power on the desired transmitter. But this scheme has limitations when the hosts are in higher mobility.

A similar report is presented in [61], where the pedestrian mobility along with a low power-update rate is considered. The shortcomings in [20] are overcome under this scheme, where a system could achieve its higher capacity level than that either in DCA or in PC. These integrated algorithms are very robust at higher degrees of mobility but a higher cost is needed for reassignment due to the motion of the users.

A simple Kalman filter has designed under an integrated dynamic channel and power allocation (DCPA) [81] that provides the measurement of both the channel gains and the interference power among nodes. As in [61], the reassignment cost being used here by a system-level simulation under the impression of dynamic user arrivals, departures, and mobility. The author claimed that the DCPA scheme performs better call droppings, call blockings and a fewer channel reassignments are required.

In [44], power control with channel-assignment algorithms are proposed for ad hoc networks with packetized data traffic. The performance of the algorithms is evaluated in terms of the total throughput. Two types of queue are introduced, FIFO and priority queues, where FIFO tries to transmit the earliest data and priority queues tries to transmit the data packets with priority first. For channel selection, the least interference method in [33] is used. When a transmitter observes high interference in the channel, then it backs off from transmission provided that the data is not time sensitive. Otherwise, it will have spent a lot of power to overcome the interference and transmit a packet to the receiver successfully. This keeps the interference level low and enables the network to admit a new link with time-sensitive data packets. But [44] deals only with single channel ad hoc networks which is not very practical.

Power-control is also incorporated with some DDCA algorithms [20], [29], but successful incorporation is impossible due to the near-far distance matter. Because it is very difficult to understand whether nodes are very far using higher power rates or nodes are very close using low power. Chuang et al. significantly reduced call interruptions by integrating an autonomous algorithm.

In [47], the authors have studied a power control and channel assignment algorithm to minimize transport power per bit by finding minimum incremental power, and compared this with least interference algorithms. This is not a distributed algorithm but can be used as an upper bound to the performance of the distributed algorithm.

In the milestone paper [33], the authors first found out that call dropping occurs when the same channel is activated within a vulnerable geographical region within the call. In this paper, two channel-assignment algorithms are introduced i.e., the Independent Algorithm (IA) and the Paired Duplex Algorithm (PDA). The goal of these algorithms is to maximizing the throughput of the networks while maintaining the required interference and SINR on every links. The independent algorithm (IA) measures channels in sequence and the least interference channels (LIC) are selected by measuring the interference level of all the outbound links as well as if the interference level is below the threshold value. In IA algorithm a lot of call dropping happens due to the existence of vulnerable region at the receiver end.

The other algorithm PDA significantly reduces call dropping by pairing two channels before commencing a call. The forward links being selected by selecting the least interference channels (LIC) as in IA, provided the mean interference level at both the forward and reverse links is below the interference threshold as well as the SINR value is above the MINSINR at both the transmitter and receiver. Unlike IA, here the vulnerable region is omitted, thus the call dropping is reduced extensively. In fact, call blocking will be increased only slightly because more forward link is not accepted by the receiver due to the SINR level at the receiver, which is the desired goal by the authors. After selecting the LIC channel a power-control algorithm is applied to the PDA algorithm to adjust the transmitter power which dramatically increases the power savings. Thus, the PDA scheme increases the network capacity by a factor of 3 over the best previous algorithms.

# 6 Concluding Remarks

Wireless Ad hoc networks are one of the most promising communication techniques in present and forthcoming generation of exponential-growth demand in network communication. This is because of its smaller size, portability, non-infrastructure, fast installation, fault tolerance, connectivity, mobility, and cost [5].

Owing to the fact that in ad hoc networks the nodes are mobile and sizes are small, these nodes introduce limitations to the power capacity as well as their transmission range. On the other hand, the nodes of ad hoc networks have limited bandwidth which introduces channel-assignment constraints which are necessary, so that collisions of packets and call droppings can be reduced significantly. These are the critical problems that may reduce the battery life and hence degrade the network capacity and throughput.

The above challenges were reviewed in this survey that investigated several trends of approaches in channel-assignment and power-control techniques in wireless ad hoc networks. Zhu in [106] states that "By transmitting a probing signal in a channel and measuring the signal-to-interference-ratio (SIR), a wireless node can estimate channel admissibility and predict its required transmission power without powering up". This scheme allows a transmitter and its respective receiver to probe a channel, to estimate the channel condition or channel admissibility and to meet the target signal-to-interference ratio (SIR). Thus for a given link a best channel can be chosen by executing the probing scheme algorithm in that link. Wu in [101] states that "It mandates that the channel assigned to a host must be different from those of its two-hop neighbors". Their new MAC protocol guarantees this property, a large amount of update messages will be sent whenever a host determines any channel change on its two-hop neighbors.

To improve the network capacity, Lin [57] states that "in PCMAC protocol the sender uses only the needed power level to transmit a packet, while the DATA/ACK collision at the receiver/sender side can still be avoided". So the channel utilization will be higher. Agarwal [1] states that "When a power-control is administered, a transmitter will use the minimum transmit power level that is required to communicate with the desired receiver". This improves both the bandwidth and energy consumption.

In [33], Grace states that "Some DDCA algorithms have also incorporated power control, but successful incorporation can be difficult due to the near-far effect". This near-far effect has avoided by two algorithms under the DDCA scheme, the independent algorithm (IA) measure channels in sequence and the least interference channel (LIC) is selected providing the interference level is below the interference threshold value. The second is the paired duplex algorithm (PDA), where channels are selected on the basis of least interference channel as well as the interference level at both the forward and reverse channel must be below the interference threshold, thus call dropping reduces significantly at the transmitter. After the initial channel selection has taken place, a power-control algorithm is then applied to the PDA algorithm, called paired duplex algorithm with power control (PDA-PC) which adjusts the transmitter power accordingly.

The authors of [33], strongly claim that "The algorithms introduced here, significantly improve capacity/performance by virtually eliminating call dropping, by pairing channels, by checking interference level on both outbound and inbound channels at both end of the link." They further claimed that "Call dropping performance of the algorithm is maintained even in the presence of log-normal shadowing, thereby eliminating near-far problems associated with many DDCA algorithms." Throughout the investigation in this survey and the remarkable impact of [33] indicates that the output of the research [33] significantly contributes and fits in the development of our survey topic.

Integration of power-control and channel-assignment is still under investigation and development phase and lots of work has yet to be done. There are several features, which needs in-depth attention and research. Some of the important and essential research topics for future directions can be included here as mentioned in the existing literature. In [81], the author suggests that "one may try to design adaptive algorithms where the parameters of the algorithm and even the power update rates are adaptively adjusted for individual users, according to such information as user movements, etc."

Agarwal [1], states that their implementation result can lead to several interesting future directions. Particularly, "in expanding the purview of the power study to include source coding, which, in the tree topology, will allow us to trade some energy for reducing the data rate at higher levels in the network." The authors in [17], suggest for future direction that "to investigate how the choice of the power level would interact with such parameters as the performance of the protocol, the lifetime of the network and the connectivity of the network."

All the way through this survey an attempt has been taken to explore and recognize the research activity that has been going on the subject of integration of channel-assignment and power-control in Wireless Ad Hoc Networks. The related research papers have been studied and brief argument has been made by comparing the output of different researchers in their study and investigation.

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# Appendix - I

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[101] Wu S.L.; Lin C.Y.; Tseng Y.C.; Sheu J.L.; "A new multi-channel MAC protocol with on-demand channel-assignment for multi-hop mobile ad hoc networks", *Parallel Architectures, Algorithms and Networks, Proc. Int'l Symposium on,* Dec. 2000, Page(s):232 – 237.

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[105] Zhu C.; "Medium access control and quality-of-service routing in mobile ad hoc networks", *PhD thesis, Department of Electrical and Computer Engineering, University of Maryland, College Park, MD 2090.*, June 2001.

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[107] Kulkarni G.; Srivastava M.; "A Channel Assignment Scheme for FDMA based Wireless Ad Hoc Networks in Rayleigh Fading Environments", *Vehicular Technology Conference, 2002. Proceedings. VTC 2002-Fall. 2002 IEEE 56th*, Vol: 2, 2002, Page(s): 1082-1085.

# Appendix - II

## Annotated Bibliography of Important Papers

[1] Agarwal S.; Katz R.H.; Krishnamurthy S.V.; Dao S.K. "Distributed power-control in ad-hoc wireless networks", Personal, Indoor and Mobile Radio Comm., 2001 12th IEEE Int'l Symposium on, 2001, Page(s): F-59 -F-66.

The authors of this paper propose a methodology i.e. a power-control loop algorithm to reduce energy consumption. Their algorithm allows all nodes to communicate with their neighbors, by choosing different transmit power levels for each of them. Thus the interference will be reduced which in turn reduce the power consumption. They claim from their simulation results that this power-control loop methodology improves energy consumption by 10-20% and increase the overall throughput by 15%.

[2] Butala A.; Tong L.; "Dynamic channel allocation and optimal detection for MAC in CDMA ad hoc networks", Signals, Systems and Computers, Conf. Record of the Thirty-Sixth Asilomar Conf. on, Vol: 2, Nov. 2002, Page(s): 1160 – 1164.

In this paper authors propose a new medium access control (MAC) protocol for wireless ad hoc networks, called Dynamic Channel Allocation (DCA), which assigns channels on-demand in a network. When a node in a network has a packet to transmit, only then the DCA allocates channels to that node in a dynamic fashion as well as avoid problems of collision associated with the hidden and/or exposed nodes. Using the combination of RTS-CTS messaging, a query packet, and a busy tone, DCA provides higher throughput than the other existing techniques. They also claim that DCA is the first MAC protocol where channel allocation is done based on the feedback of contention information that occurs at the receiver. The receiver's feedback information to transmitters helps to select a channel for transmission if it does not cause any contention at any of the neighboring receivers. By assigning cannels dynamically, DCA offers improved throughput normalized by available bandwidth. The author alleged that this technique of channel assignment ensures the perfect reception of data-packets under ideal conditions.

[3] Butala A.; Tong L.; "Dynamic channel allocation and optimal detection for MAC in CDMA ad hoc networks", Signals, Systems and Computers, Conf. Record of the Thirty-Sixth Asilomar Conf. on, Vol: 2, Nov. 2002, Page(s): 1160 – 1164.

The authors of this paper propose a new MAC protocol for multi-hop ad hoc networks. This new MAC protocol referred to as Dynamic Channel-assignment (DCA) which allocates channels on-demand. A two-way handshaking (RTS-CTS) messaging technique with a query packet and a busy tone is being used in DCA scheme. It is found that DCA is a collision-free MAC protocol with high value of throughput than the existing corresponding techniques. They also claim that only DCA is the first MAC protocol that assigns channels on the basis of interference type at the receiver. Their experimental result shows that with the detection of interference at the receiver ensures the perfect reception data-packets under ideal conditions.

[4] Chang C.Y.; Chang C.T.; Huang P.C.; "Dynamic channel-assignment and reassignment for exploiting channel reuse opportunities in ad hoc wireless networks", Communication Systems, The 8th Int'l Conf. on, Vol: 2, Nov. 2002
Page(s): 1053 – 1057.

The authors of this paper investigate the channel-assignment and re-assignment problem in Mobile Ad Hoc Networks. They propose a channel-assignment protocol so that the channel resource will be highly utilized. They also proposes a channel reassignment protocol which will prevent the co-channel interference when one pair of communicating host becoming closer (within transmission range) to another pair of hosts of using same channel. Their simulation and experimental results shows that channel-assignment and reassignment increase the network capacity as well as decreases the rate of call dropping among hosts.

[5] Chen B.; Jamieson K.; Balakrishnan H.; Morris R.; "An energy-efficient coordination algorithm for topology maintenance in Ad Hoc wireless networks", Proc. of the 7th annual Int'l Conf. on Mobile computing and networking, Rome, Italy, 2001, Page(s): 85 – 96.

This paper presents a power saving technique called span in wireless ad hoc networks without a significant compromise of network capacity and connectivity. The span is a randomized algorithm where nodes are themselves takes decision whether they will go for sleep or awake up to help as a coordinator for communication between two of its neighbors. They assumed that a node decide to volunteer as a coordinator if it notice that two of its neighbors cannot directly communicate to each other or with any coordinators. They demonstrate that the system lifetime with span is more than twice than that of without the span.

[6] Cheng M.M.-L.; Chuang J.C.-I.; "Performance evaluation of distributed measurement-based dynamic channel-assignment in local wireless communications", Selected Areas in Communications, IEEE Journal on, Vol: 14, May 1996, Pages: 698 – 710.

In this paper the authors present a simple aggressive algorithm known as the Least Interference Algorithm (LIA) as the best algorithm in wireless networking. They evaluate and compare several distributed measurement-based and a centralized prediction-based DCA algorithms. In LIA the instantaneous power measurement is used to select the channel with the least received interference power. The selection of least receive interference channel minimize overall interference power in the system and thus increase the network capacity. They also claim that the implementation cost can be reduced drastically due to the straight-forwardness of LIA.

[7] Cheng M.X.; "Resource efficiency in ad hoc wireless networks: Problems and solutions", Ph, UNIVERSITY OF MINNESOTA, 2003, 116 pages, AAT 3098578.

In this paper the authors investigated and modeled a new class of disk graphs for the wireless networks called interference Disk Graph (FD). In this model, graph coloring approach is applied to minimize the interference i.e. to avoid the collision. A heuristic algorithm is designed by them for graph coloring so that the direct collision and hidden terminal interference can be eliminated. Experimental results shows that the FD graph model requires less number of channels than intersection Disk (ID) and Double Disk

(DD) graph models but requires more channels than containment Disk (CD) graph models.

[8] Chiang M.; Carlsson G.; "Admission control, power-control and QoS analyses for ad hoc wireless networks", Comm., 2001. ICC 2001. IEEE Int'l Conf. on, Vol: 1, June 2001, Page(s): 245 – 249.

In this paper, authors present two power-control schemes to balance the tradeoff between link maintenance and power consumption. They considers that increasing the transmit power for a user makes the outgoing links more reliable. At the same time, it also decreases the battery life which might causes interference to other users. They claim that this algorithm balance power conservation and interference improvement on the basis of threshold phenomena with several networks performance criteria, such as robust routing, multicasting and transmission delay.

[9] Chiasserini C.F.; Rao R.R.; "A distributed power-management policy for wireless ad hoc networks", Wireless Comm. and Networking Conf., 2000. WCNC. 2000 IEEE, Vol: 3, 23-28 Sept. 2000, Page(s): 1209 – 1213.

This paper proposed a new distributed power-management scheme that maximizes the power saving without any compromise of QOS in wireless ad hoc networks. In this scheme, a power device could be activated remotely by any sort of waking-up signal using a simple RF tag technology. In that way a node may enter in sleep state if it is not currently used. On the other hand a node will wake up when traffic is yet to transmit by this node. Again a node can select a sleep pattern as per its QOS and battery status, as well as it can enter a sleep state only if they are idle. At heavy traffic load a 24% of power gain is possible to obtain in this scheme.

[10] Chuang J.C.-I.; Sollenberger N.R.; "Performance of autonomous dynamic channel-assignment and power-control for TDMA/FDMA wireless access", Selected Areas in Communications, IEEE Journal on, Vol.: 12, Issue: 8, Oct. 1994, Page(s): 1314 – 1323.

The authors of this paper combine autonomous algorithms for dynamic channel-assignment (DCA) and power-control in a TDMA/FDMA wireless system. The DCA algorithm is based on the determination of paired channels that have very low level of interference or they have very low possibility of causing interference. On the other hand the power-control algorithm uses local estimations of signal-to-interference-ratio (SINR) at a receiver which leads to adjustment of power on the desired transmitter. They claim that using of DCA and SIR-based power control, the TDMA/FDMA can achieve a reasonable capacity like CDMA system till traffic servers are available.

[11] ElBatt T.; Ephremides A.; "Joint Scheduling and Power-control for Wireless Ad Hoc Networks", Wireless Comm., IEEE Transactions on, Vol: 3, Issue: 1, Jan. 2004, Page(s): 74 – 85.

Here the authors introduce a cross-layer design framework for limiting the multi-user interference to increase single-hop throughput and reducing power-control to increase the battery life. Mainly the next neighbor transmissions are focused where transmitters send packets to their respective receiver on the basis of SINR. They solve the power-control problem in two phases until a set of users and their respective set of powers can not be found. In the first phase, a simple scheduling algorithm eliminates the strong level of interference which can not be eliminated by power control. In the 2nd phase, a distributed power-control algorithm determines the set of powers which could be used by the users.

[12] ElBatt T.A.; Krishnamurthy S.V.; Connors D.; Dao S.; "Power-management for throughput enhancement in wireless ad-hoc networks", Comm., IEEE Int'l Conf. on, Vol: 3, June 2000.

In this paper, the authors first introduce the concept of power-management scheme in wireless ad hoc networks. This power-management scheme is used in corporation with traditional routing protocols without any major modification to the protocols themselves. They also defined the notion of clusters where a node might want to communicate by adjusting the power or might use fixed power to communicate all the nodes. They found

that the former scheme performs better average power consumption and a higher end-to-end throughput.

[13] Gomez J.; Campbell A.T.; Naghshineh M.; Bisdikian C.; "Conserving transmission power in wireless ad hoc networks", Network Protocols, 2001. Ninth Int'l Conf. on, 11-14 Nov. 2001, Page(s): 24 – 34.

The authors present a power-aware routing optimization technique, PARO, that helps to minimize the transmit power required for wireless networks. In PARO, the intermediate nodes work as a redirector to forward packets or data between source-destination pairs. The forwarding technique reduces the overall transmission power, thus increasing the overall lifetime of the network devices. They argue that PARO significantly reduces the aggregate transmission power, because PARO is based on the principle that it adds only the additional redirector nodes to maximize the numbers between source-destination pairs. Thus this approach leads the nodes to be dynamically capable of adjusting their transmission power on per-packet basis. They evaluate the performance between PARO and MLSR and shows that PARO consumes less power in order to find an efficient route.

[14] Grace, D.; Tozer, T.C.; Burr, A.G.; "Reducing call dropping in distributed dynamic channel-assignment algorithms by incorporating power-control in wireless ad hoc networks", Selected Areas in Comm., IEEE Journal on, Vol: 18, Issue: 11, Nov. 2000, Page(s): 2417–2428.

The authors of this paper present the methods that use Distributed Dynamic Cannel Assignment (DDCA) scheme where power-control is incorporated with channel-assignment algorithms. In their discussions they found that call dropping occurs when same channel activated within a vulnerable geographical region within the call. This scheme is developed with the help of mathematical analysis and a novel pictorial model which use variable transmitter power to neutralize the effect of shadowing environment. There are two algorithms under the DDCA scheme, the independent algorithm (IA) measure channels in sequence and the least interference channel (LIC) is selected providing the interference level is below the threshold value. The second is the paired

duplex algorithm (PDA), which significantly reduce call dropping providing the SINR value is above the MINSINR. After the initial channel selection has taken place, a power-control algorithm is then applied to the PDA algorithm which adjusts the transmitter power. They argue that this scheme additionally increase the network capacity by a factor of 3 over the best previous algorithms.

[15] Hać A.; Chen Z.; "A hybrid channel allocation method for wireless communication networks", Int'l Journal of Network Management, Vol: 10, March–April 2000, Page(s): 59 – 74.

A new hybrid method for channel-assignment has introduced in this paper which gives better performance under heavy traffic load environment. The authors mentioned that this method is very different with other as usual hybrid method in respect of two aspects. First one, it emphasizes not only the dynamic channel allocation part but also the nominal channel allocation part. This method become consistent by minimizing the co-channel reuses distance in both parts of the methods. Secondly, the channel's already assigned as nominal channels can be reassigned as dynamic channels to calls for other user, until the channel separation constraint dissatisfied. The simulation results shows when the traffic load increases, the percentage of blocking channel rate for their method increases very slowly than for the traditional methods.

[16] Jin K.T.; Cho D.H.; "A new MAC algorithm based on reservation and scheduling for energy-limited ad-hoc networks", Consumer Electronics, IEEE Transactions on, Vol: 49, Issue: 1, Feb. 2003, Page(s): 135 – 141.

The authors of this paper propose an energy-efficient MAC algorithm based on the reservation and scheduling in wireless single-hop ad hoc networks. To describe this algorithm they emphasizes that for the heavy traffic load the proposed MAC scheme protects mobile terminal from collisions and retransmissions which increases the power consumption savings. They allege that the proposed MAC algorithm informs each terminal or node when to wake up from idle mode or when to go to idle mode to save power.

[17] Jung E.S.; Vaidya N.H,; "A power-control MAC protocol for ad hoc networks", Int'l Conf. on Mobile Computing and Networking, Proc. of the 8th annual Int'l Conf. on Mobile computing and networking, Atlanta, Georgia, USA , 2002, Page(s): 36 – 47.

The authors propose a power-control MAC protocol referred to as the BASIC scheme that is based on the RTS-CTS handshaking protocol. In this scheme, different power levels are being used for RTS-CTS and DATA-ACK. In this context, the RTS-CTS are transmitted using the highest power levels and DATA-ACK are transmitted using minimum power levels in order to save energy or battery life. They declare that this scheme has some short comings such that it degrade network throughput and can result in higher energy consumption. To overcome this drawback they propose a new power-control MAC protocol, PCM which achieves energy savings without causing throughput degradation.

[18] Kawadia, V.; Kumar, P.R.; "Power-control and clustering in ad hoc networks", Twenty-Second Annual Joint Conf. of the IEEE, Computer and Comm. Societies. IEEE, Vol: 1, March - April 2003, Page(s): 459 – 469.

The authors of this paper propose three protocols to solve the power-control problem, when nodes are non-homogeneously or clustery spread over the network space, are CLUSTERPOW, Tunneled CLUSTERPOW and MINPOW. Their main goal was to choose a power level so that all the intra-cluster communication is possible with a lower transmit power level and all the inter-cluster (different cluster) communication use a higher transmit power level. It is claimed that CLUSTERPOW increase the network capacity by reducing the power consumed in individual cluster base, whereas MINPOW provides an optimal routing solution with respect to total power consumed globally.

[19] Keszei, C.; Imre, S.; "Simple resource reservation in ad-hoc networks", Personal, Indoor and Mobile Radio Comm., The 13th IEEE Int'l Symposium on, Vol: 2, Sept. 2002, Page(s): 715 – 719.

In this paper, authors introduce a novel concept called Distributed Call Reservation Scheme (DVRS) which overcome the at least two problems arise in the two-way

handshake protocol technique with carrier sense. They explained those two problems as; firstly what happens if two transmissions are started at the same time; secondly what happens if there is a hidden or exposed node arise. To resolve these problems they have extended two-way handshake to four-way handshake. Sender sends a small packet called RTS before data transmission which carries the destination address and length of data to be transmitted. If two nodes send this packet same time then only these small packets destroyed. After decoding this RTS packet, receiver responds with a small CTS packet. The remaining process is a data transmission-acknowledge two-way handshake. Thus the typical hidden node problem resolved

[20] Kim J.W.; Bambos N.; "Power-efficient MAC scheme using channel probing in multirate wireless ad hoc networks", Vehicular Technology Conf., 2002. Proc.VTC 2002-Fall. 2002 IEEE 56th, Vol: 4, Sept. 2002, Page(s): 2380 – 2384.

In this paper a power MAC protocol is proposed. It is a combination of the Distributed Power-control with Active Link Protection (DPC/ALP) and a probing scheme that predict a mobile's SIR evaluation. The above suite can deliver an extremely short session without excessive delay in the power-up phase. This protocol accomplishes the fairness of the ad hoc network by a flow control technique, called pipelining. In pipelining, channel is shared by limiting the channel occupancy time because length of the session is limited. The author claimed that the proposed protocol can save power more than 20 dB in light network traffic.

[21] Kulkarni, G.; Raghunathan V.; Srivastavaand M.; Gerla M.; "Channel allocation in OFDMA based wireless ad hoc networks", Electrical Engineering Department, Computer Science Department, University of California, Los Angeles (UCLA)., 2002, Page(s): 1082 – 1085.

This paper is a study of Orthogonal Frequency Division Multiple Access (OFDMA) protocol for ad hoc networks. This OFDM modulator makes it possible the simultaneous transmission for each point-to-point link by using a subset of the total number of available bandwidth. Authors of this paper presented a distributed algorithm on the basis

of hierarchical clustering for bandwidth allocation. This protocol is robust and scalable which enables flexible network resource management as it has the ability to vary the output link capacity.

[22] Kulkarni G.; Srivastava M.; "A channel-assignment scheme for FDMA based wireless ad hoc networks in Rayleigh fading environments", Vehicular Technology Conf., Proc. VTC 2002-Fall. 2002 IEEE 56th, Vol: 2, Sept. 2002, Page(s): 1082 – 1085.

The authors of this paper address the problem of channel-assignment for wireless ad hoc networks that use FDMA. An adaptive modulation is applied to satisfy the data rate requirement for every transmitter-receiver pair. Again power-control is also necessary in order to maintain the required signal to interference ratio (SINR) which arose due to the channel reuse. This helps us to minimize the total transmission power in the entire network while maintaining data rate requirement satisfiable.

[23] Lin X.H.; Kwok Y.K.; Lau V.K.N.; "Power-control for IEEE 802.11 ad hoc networks: issues and a new algorithm", Parallel Processing, Proc. 2003 Int'l Conf. on, Oct. 2003, Page(s): 249 – 256.

The authors of this paper propose a new MAC protocol called PCMAC (Power-control MAC) which is an enhancement of the original MAC protocol in the IEEE 802.11 standard. They also focused that PCMAC can effectively minimize the asymmetrical link problem arisen in all other existing power-control scheme. This scheme suggests that the sender uses only the normal power level during handshaking mechanism while use the needed power level during data transmission and the sender should raises to maximal value randomly. Thus the asymmetrical problem is tackled satisfactorily and battery power saved which reduces the co-channel interference significantly and thus improving the network capacity.

[24] Lloyd E.L.; Liu R.; Marathe M.V.; Ramanathan R.; Ravi S.S.; "Energy Awareness and Power Control: Algorithmic aspects of topology control problems for ad hoc networks", Proc. of the 3rd ACM Int'l symposium on Mobile ad hoc networking & computing, Lausanne, Switzerland, 2002, Page(s): 123 – 134.

A study of the topology control problem is performed with a motivation to make efficient use of available power at each node to decrease the MAC layer interference between adjacent nodes. The topology control problem was based on different optimization objectives like minimizing maximum power and minimizing the total power. They present a polynomial general approach algorithm for a class of graph properties called monotone properties to minimize the maximum power. Another approximation algorithm is used to minimize the total power for some monotone properties.

[25] Lozano A.; Cox D.C.; "Integrated dynamic channel-assignment and power-control in TDMA mobile wireless communication systems", Selected Areas in Comm., IEEE Journal on, Vol: 17, Issue: 11, Nov. 1999, Page(s): 2031 – 2040.

This paper is an investigation of the integration of Dynamic Channel-assignment (DCA) and Power-control (PC) algorithms while the pedestrian mobility along with a low power update rate is considered. Three different types of minimum interference DCA algorithms has presented with power-control which are fully distributed, cost adaptive, achieves higher capacity levels than those system either in DCA or in PC. They claim that their integrated algorithms are very robust at higher degrees of mobility although the compromising of reassignment cost increased with motion.

[26] Montemanni R.; Smith D.H.; Allen S.M.; "An ANTS algorithm for the minimum-span frequency-assignment problem with multiple interference", Vehicular Technology, IEEE Transactions on, Vol: 51 ,Issue: 5, Sept. 2002, Page(s): 949 – 953.

This paper is a study of minimum-span frequency-assignment problem (MS–FP) which is a meta-heuristic algorithm. This MA-FAP algorithm is based on the function of real ant colonies computational paradigm. While most of the existing algorithms for frequency

assignment problem approached on single interference, only MS-FAP take into consideration of multiple interference with minimize the span. They claim that their computational results are very promising and it outperforms the existing algorithms with all benchmarks except with the large dimension of problem.

[27] Ramanathan S.; "A unified framework and algorithm for channel-assignment in wireless networks", Wireless Networks, Vol: 5, March 1999, Page(s): 81 – 94.

In this paper the authors present two centralized algorithms for use in wireless ad hoc networks. They formulate the power-control problem in two constraints such as connectivity and bi-connectivity, and one objective of maximum power optimality. They also present two distributed heuristic algorithms that adaptively adjust the transmit power of each node which ultimately reduce the power consumption. They allege that these heuristics are widely applicable in ad hoc networks for their capability to increase the network capacity, battery life and connectivity.

[28] Shoarinejad K.; Speyer J.L.; Pottie G.J.; "Integrated predictive power-control and dynamic channel-assignment in mobile radio systems", Wireless Communications, IEEE Transactions on, Vol.: 2, Issue: 5, Sept. 2003, Page(s): 976 – 988.

In this paper, the authors propose an integrated dynamic channel and power allocation (DCPA) scheme on the basis of a novel predictive power-control algorithm in an FDMA/TDMA mobile system. They designed a simple Kalman filters that provides the measurement of both the channel gains and the interference power. Then the predicted measurements are applied to an integrator algorithm to update the power levels of all the users in the network. Authors also presented a system-level simulation platform under the dynamics of user arrivals, departures, and mobility. Their simulation analysis shows that the predictive DCPA scheme performs of better call droppings, call blockings and a fewer channel reassignments are required.

[29] So J.; Vaidya N.H.; "A Multi-channel MAC Protocol for Ad Hoc Wireless Networks", Department of Computer Science and Computer Eng., University of Illinois, Technical Report, January 2003.

To improve the network capacity further a Multi-Channel MAC (MMAC) protocol is proposed in this paper. Since IEEE 802.11 standard protocol offer multiple channels for use but its MAC protocol is designed only for a single channel. This MMAC protocol modifies the IEEE 802.11 DCF protocol to enable hosts to utilize multiple channels by switching the channels dynamically. It is claimed by the authors that this protocol is an improvement over single-channel MAC protocol as well as over the existing multi-channel MAC protocol.

[30] Spyropoulos A.; Raghavendra C.S.; "Energy-efficient Comm. in ad hoc networks using directional antennas", INFOCOM 2002. Twenty-First Annual Joint Conf. of the IEEE Computer and Comm. Societies. Proc.IEEE, Vol: 1, June 2002, Page(s): 220 – 228.

An energy-efficient routing and scheduling algorithm is proposed for using of directional antennas in unidirectional ad hoc networks. It is a four step algorithm that coordinates transmissions where every node has a single directional antenna. This algorithm first performs energy-efficient routing to find the minimum energy paths and then perform schedule of nodes transmissions. Mainly the scheduling step minimizes the amount of time it takes to communicate all transmitter-receiver pairs. They argue that their algorithm achieves all the possible gain in transmitter-receiver communication using directional antennas. Again they claim that another 45% improvement in network lifetime is achieved by energy-aware routing.

[31] Sun J.; Hu Y.; Wang W.; Liu Y.; "Channel access and power-control algorithms with QoS for CDMA based wireless ad-hoc networks", Personal, Indoor and Mobile Radio Comm., 14th IEEE Proc. on, Vol: 2, Sept. 2003, Page(s): 1079 – 1084.

In this paper the authors propose a distributed channel access and power-control algorithm in CDMA environment. They studied two algorithms; distributed channel

access with active link protection (DCA/ALP) and distributed power-control with adaptive protection margin (DPC/APM). The test results of their simulation demonstrate that the above suite of algorithms is more effective to save power than traditional one. As a result it ultimately increases the network capacity.

[32] Toh C.-K.; "A Local Decision Algorithm for Maximum Lifetime in Ad Hoc Networks", Communications Magazine, IEEE, and Vol.: 39, Issue: 6, June 2001, Page(s): 138 – 147.

In this paper, the author propose a novel routing algorithm called ME+LA, abbreviated as Minimum Energy with Locally Select algorithm. This algorithm allows each host to locally select next host, having only the idea of the remaining battery capacity of the neighbor nodes such that capacity does not fall in it's transmit coverage range. They claim that this algorithm optimize the system life time until the first neighbor host drains-off its battery.

[33] Tseng Y.C.; Wu S.L.; Lin C.Y.; Sheu J.P.; "A multi-channel MAC protocol with power-control for multi-hop mobile ad hoc networks", Distributed Computing Systems Workshop, 2001 Int'l Conf. on, April 2001, Page(s): 419– 424.

This paper is an investigation of the possibility of how to utilize the available channels efficiently and how to resolve the existing contention and collision among mobile hosts under MAC protocol. Their MAC protocol named DCA-PC (dynamic channel-assignment with power control). It is an extension of the earlier DCA protocol in [9], which does not take power-control into consideration. This protocol assigns channel to the mobile hosts on an on-demand manner. It flexibly adapts to host mobility without the requirement of any form of clock synchronization. An improve network throughput is possible with multi-channel MAC protocol because multiple transmission can take place without interfering each other.

[34] Wang K.; Chiasserini, C.F.; Rao, R.R.; Proakis, J.G.; "A distributed joint scheduling and power-control algorithm for multicasting in wireless ad hoc networks", Comm., ICC '03. IEEE Int'l Conf. on, Vol: 1, 2003, Page(s): 725 – 731.

This paper addressed the power-control problem in ad hoc networks that support multi cast communication. Authors of this paper proposed two algorithms; first a distributed power-control scheme, second a distributed joint scheduling and power-control algorithm. First scheme provides an optimal solution that minimizes the power consumption incorporation with the desired SINR at the receivers. The second algorithm solves some of the specified power-control problem by eliminating the comparatively strong interferences.

[35] Wang S.C.; Wei D.S.L.; Kuo S.Y.; "A topology control algorithm for constructing power efficient wireless ad hoc networks", Global TeleComm. Conf., 2003. GLOBECOM '03. IEEE, Vol: 3 , 1-5 Dec.2003, Page(s): 1290 – 1295.

A localized power-efficient distributed algorithm where only the local information requires constructing and maintaining a logical topology on the unit disk graph. This algorithm first constructs a Gabriel graph from the available unit disk graph and then the aggregate power is reduced by replacing the critical links by replaceable paths. They also claim that this algorithm requires very less time to solve a problem which in turn further reduces the power consumptions for each mobile node.

[36] Wattenhofer R.; Li L.; Bahl P.; Wang Y.-M.; "Distributed topology control for power efficient operation in multihop wireless ad hoc networks", INFOCOM 2001. Twentieth Annual Joint Conf. of the IEEE Computer and Comm. Societies. Proc. IEEE, Vol: 3, 22-26 April 2001, Page(s): 1388 – 1397.

The authors of this paper introduces a novel cone-based topology control algorithm that determines the minimal power consumption for each node in a multi hop wireless ad hoc network. In this algorithm each node takes local decisions by itself about the transmit power which collectively reach towards global connectivity. A node gets the directional information of its closer neighbor nodes around all direction and increase it's transmit power until a node is discovered. This leads to multi hop connectivity where the power consumption is lower. Furthermore they present an approximation scheme where the

power consumption of each route can be closer to the optimal value by carefully choosing the network parameters.

[37] Wu S.L.; Lin C.Y.; Tseng Y.C.; Sheu J.L.; "A new multi-channel MAC protocol with on-demand channel-assignment for multi-hop mobile ad hoc networks", Parallel Architectures, Algorithms and Networks, Proc. Int'l Symposium on, Dec. 2000, Page(s): 232 – 237.

In this paper, the authors propose a new multi-channel MAC protocol based on the mechanism of two-way handshaking (RTS/CTS) reservation. This protocol can be applied to both TDMA and CDMA technology but in this approach each mobile host needs two transceivers. They said that this protocol dynamically assigns channels to mobile host in an on-demand manner. They also claim that it does not use any form of clock synchronization among mobile hosts and it is completely degree-independent protocol. This protocol not only solves the channel-assignment problems but also the medium access problems are solved. Their simulation results shows that under heavy loaded traffic environment this protocol faces less degradation and it out performs the single-channel counterpart.

[38] Wu S.L.; Lin C.Y.; Tseng Y.C.; Sheu J.L.; "Intelligent medium access for mobile ad hoc networks with busy tones and power control", Computer Comm. and Networks, Proc. Eight In'l Conf. on, Oct. 1999, Page(s): 71 – 76.

The authors of this propose a new MAC protocol that combines the intelligence of power control, RTS-CTS dialogue, and busy tones to increase the channel utilization. In their protocol a sender will use relatively low power level so that the channel reuse will be increased. The increment of channel reuse also saves the battery life and reduces co-channel interference among other hosts. They also show that this power-control protocol can help to enhance the performance of a MANET.

[39] Zhu C.; ”Medium access control and quality-of-service routing in mobile ad hoc networks”, PhD thesis, Department of Electrical and Computer Engineering, University of Maryland, College Park, MD 2090., 2001-6.

In this Ph.D. thesis, the author studied some of the channel-assignment scheme and made a trade-off comparison between their performances. They are; Random Channel Selection (RCS), Sensing-based Channel Selection (SCS), and Probing-based Channel Selection (PCS). The author described that in RCS and SCS, a link determines its admissibility to a channel in “the hard way”, which can increase the interference dramatically to on-going transmissions and force some transmissions to be dropped. On the other hand, he claims that in PCS scheme the interference caused to other links is reduced significantly, because in PCS, the link is blocked without further trying to power-up in any of the channel if all the channels are inadmissible. It shows that the performance of the RCS scheme is worst in all aspects of performance measures.

[40] Zhu C.; Corson M. S.; “A distributed channel probing scheme for wireless networks”, Twentieth Annual Joint Conf. of the IEEE Computer and Comm. Societies. Proc. IEEE, Vol: 1, April 2001, Page(s): 403 – 411.

The authors of this paper present a distributed channel probing scheme called Probing Channel Selection (PCS) scheme which can be used as a part of the dynamic channel allocation scheme. This new scheme allows a transmitter and it’s respective receiver to probe a channel, to estimate the channel condition or channel admissibility and to meet the target signal-to-interference ratio (SIR). Thus for a given link a best channel can be chosen by executing the probing scheme algorithm in that link. The authors claims that their simulation results shows that in this new scheme the newly arrived calls faces less blocking experience and less disruptions.

# Appendix - III

## Leading Researchers List

1) Amit Butala
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# Appendix - IV

## List of Most Recent and Future Conferences

1) INTERNETWORKING 2004
Technical Program: May 13-14, 2004
Las Vegas, Nevada
http://www.caitr.org/internetworking04/

2) IEEE Radio and Wireless Conference RAWCON 2004
19 - 22 September 2004
Atlanta, GA USA
http://www.rawcon.org/

3) IFIP/IEEE MWCN 2004
The Sixth IFIP/IEEE International Conference on
Mobile and Wireless Communications Networks
Paris, France, 25 - 27 October, 2004
http://mwcn2004.lri.fr/

4) International Workshop on Theoretical Aspects of Wireless
Ad Hoc, Sensor, and Peer-to-Peer Networks
June 11th- 12th, Chicago, Illinois, USA. Sponsored by NSF.
http://www.cs.iit.edu/~xli/workshop/

5) VANET 2004: First ACM Workshop on Vehicular Ad Hoc Networks
in conjunction with ACM MobiCom 2004
October 1, 2004
Loews Philadelphia Hotel, Philadelphia, PA, USA
http://www.path.berkeley.edu/vanet/

6) 1st International Symposium on Wireless Communication Systems 2004
20 - 22 September 2004, MAURITIUS
http://www.uom.ac.mu/events/iswcs04.htm

7) ADHOC-NOW'04
International Conference on AD-HOC Networks & Wireless
22-24, 2004, Vancouver, British Columbia
jeyanthihall@rogers.com

8) IST Mobile and Wireless Communications Summit 2004
Lyon, France
27-30 june 2004
http://www.mobilesummit2004.org/

9) The 3rd Asian International Mobile Computing Conference (AMOC 2004)
May 26-28, 2004, Bangkok, THAILAND
http://amoc2004.cpe.ku.ac.th

10) The ACM International Symposium on on Mobile Ad Hoc Networking and Computing, MobiHoc 2004, Tokyo, Japan, 24-26 May 2004
http://www.sigmobile.org/mobihoc/2002/

11) The ACM International Symposium on Mobile Ad Hoc Networking and Computing, MobiHoc 2002, Lausanne, Switzerland, 9-11 June 2002
http://www.sigmobile.org/mobihoc/2002/

12) The ACM International Symposium on Mobile Ad Hoc Networking and Computing, MobiHoc 2001, Long Beach, California, USA, 4-5 October 2001,
http://www.sigmobile.org/mobihoc/2002/

# Appendix - V

## Sample of Contact with Researchers

From: "Ivan Stojmenovic" ivan@site.ottawa.ca
Subject: RE: Survey on Wireless Ad Hoc Networks
Date: Mon,12 April 2004 09:07:02 -0400
To: N Ali<ali1e@uwindsor.ca>

Dear Ali,

Thank you for your mail to correct some error in my book "Handbook of Wireless Networks and Mobile Computing". But now the publication of this book is stop, so I don't need to correct those words or sentence.
For interesting research paper you can visit the following links:
http://dl.comsoc.org/cocoon/comsoc/servlets/GetPublication?id=149419

Again thank you for your interest.

Regards,
Ivan

----- Original Message -----
From: "Nowsher Ali" <ali1e@uwindsor.ca>
To: <ivan@site.uottawa.ca>
Sent: Thuesday, Apr 06, 2004 1:44 AM
Subject: RE: Survey on Wireless Ad Hoc Networks

>
> Dear Sir,
>
> I am doing a Masters Survey course under Dr.Ngom and Dr. Jakel and > > the topic is "Channel-assignment and Power-control in Wireless Ad hoc > networks". Dr. Ngom referred me the book "Handbook of Wireless > > > > Networks and Mobile Computing" authored by you. I have gone through > some of the chapters and I have noticed some typographical or other type of error. Which are:

> Chapter 6, Page 119 > in middle area> incorrect: "media access > > > > protocols (MAC)"
> correct : "media access control (MAC)"

> Chapter 15, Page 328 > line no. 6 from bottom> incorrect: "between > > portable computers and between portable computers and a fixed network > infrastructure".

> correct : "between portable computers and a fixed network > > > > > > > infrastructure"

> You may correct those words/sentences for the next publication.

> Being you are an expert researcher in Wireless Networking, may I > > > request you to provide me any further papers that can help me to do > > the survey.

> Thanks
>
> Nowsher Ali
> Masters Candidate
> University of Windsor

# Appendix - VI

## Cross Reference Graph

The Cross Reference Graph is attached herewith in last page. In the graph, the authors indicated in column are referred by the authors indicated in rows. The numbers mentioned in last column represented how many times those papers are referred by the authors mentioned in bottom rows.

The cross-reference graph helps the surveyor to identify the milestone and major papers related to the research topic. Since wireless ad hoc networks is a new field and then the integration of channel-assignment and power-control is the most recent research area, it is very hard to find out the Milestone and Major papers by the above criteria. Because some of the important and promising research is going on in very recent, definitely those papers are not referred by any of other researchers. In fact, by following the above criteria I have hound 20 major papers which are referred equal or more than five times by other authors. Other 20 major papers including the milestone one [33] has chosen by considering some factors that are; how important the paper, how much closely related with my topic, and the year of publication. One can read my cross-reference graph as follows:

| | | | | | |
|---|---|---|---|---|---|
| E | * | | * | * | |
| D | | | | | |
| C | | * | | | |
| B | | | | | |
| A | | * | | * | |
| | A | B | C | D | E |

***Figure 3: Sample of a Cross-Reference Graph***

In the above sample cross-reference graph, the paper 'E' is referred by A, C, D, and paper 'C' is referred by B only and 'A' is referred by B & D and B & D are not referred by any one.