Technical Term Paper

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Abstract:

An adhoc network is a collection of wireless mobile nodes dynamically forming a temporary network without the use of any existing network infrastructure or centralized administration. Due to the limited transmission range of wireless network interfaces, multiple networks "hops" may be needed for one node to exchange data with another across the network. The achievable capacity in theses networks is low and also these networks inherit the traditional problems of wireless and mobile communication, such as bandwidth optimization, power control, topology control, energy constrained operation. In this paper we show that wireless multihop networks overlaid with cellular structure have the potential to support high data rate Internet traffic. We consider techniques by which the system capacity of such networks can be increased. First, we explain the methods for increasing link capacity in single-user systems. Subsequently, we consider a different set of techniques suitable for multi-user systems. We also investigate the effect of traffic dynamics on system capacity and ways to achieve the maximum throughput. Finally, we present capacity bounds which illustrate how these techniques help in trading off the conserved power for capacity advantage.

1) Introduction:

Mobile Adhoc NETwork, also called MANET, is created for a particular purpose for information sharing between mobile nodes. Communication between two hosts in this type networks is not always direct- it can proceed in a multihop fashion so that every host is also a router. There's is no need of infrastructure. Each node is equipped with one or more radios. Each node is free to move about while communicating. Paths between nodes can be multi-hop. In single-hop networks the data packets are transmitted from source to destination in one hop without using intermediate nodes. In a multihop network no node is distinct from the other and data transmission to remote stations is possible via several hops. Terminals in this type of network mainly rely on short life-time batteries, and therefore, energy conservation is a critical design criterion. So considerable research and development has been undertaken to extend wireless communication to encompass wireless Internet. Among these recent technologies, ad hoc networks and similar systems (e.g., Bluetooth-based piconets, Metricom's Ricochet) exemplify the progress in providing broad connectivity based on multihop technology.

In mobile adhoc network, it is often more important to optimize for energy efficiency than throughput. Many papers [3] were published on this topic to optimize the energy efficiency. But the achievable capacity in these networks is low as demonstrated by simulation studies and as supported by analytical work. Recently, power control and rate adaptation techniques have been proposed and shown demonstrative improvements on network capacity. The high propagation loss on radio links normally requires a high power at the transmitter and hence a high total consumed power. In our paper we show that the transmit power may be reduced by breaking down the distance between two communicating points into smaller segments. This is accomplished by routers that establish the path between mobile terminals and base stations subject to the constraints and requirements imposed by the network.

We can improve the capacity of wireless cellular networks by increasing the number of channels in the space by reducing the cell size. However, this won't be effective as small cells are not often desirable, as base stations and their interconnections to the wired backbone are costly. So here, as depicted in figure 1, we consider adding inexpensive wireless routers to the conventional network structure to increase the system capacity

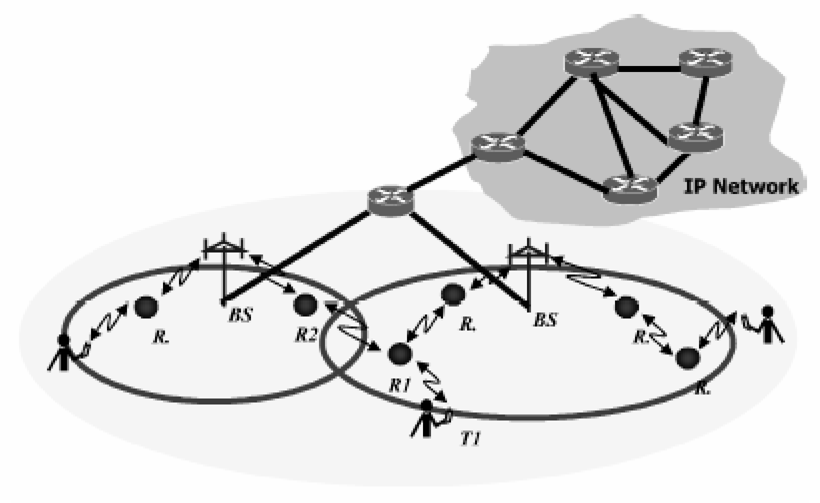
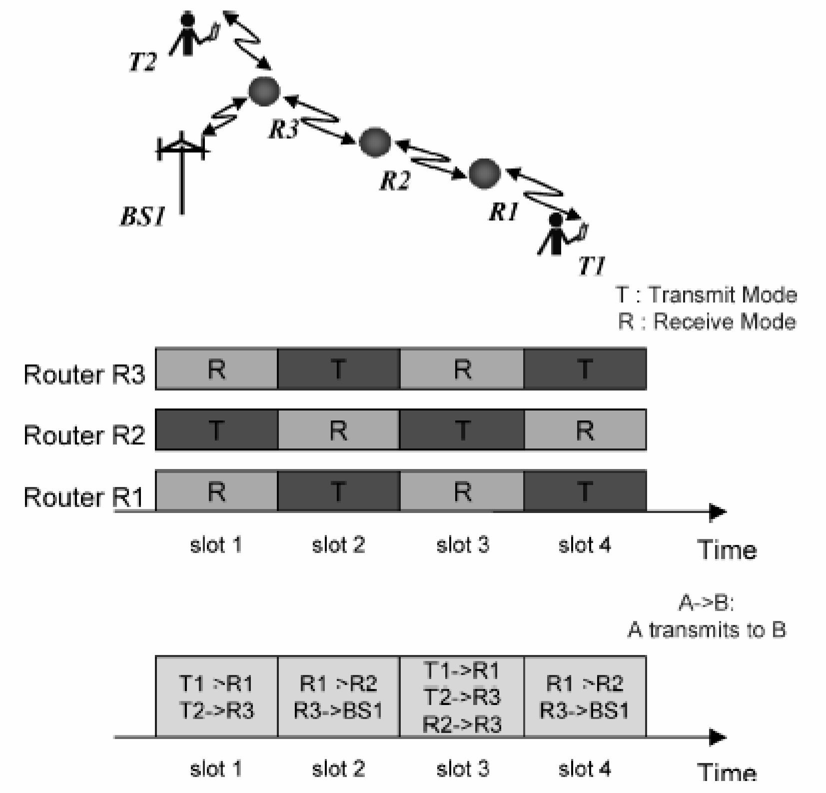


Figure 1. Network structure: base stations (BS), routers (R) and terminals (T) are distributed uniformly in the network. Terminals in a cell might transmit to a base station in another cell based on the routing strategy.

But by simply adding routers to the current cellular networks may not improve the throughput, since relaying the packets artificially increases the total traffic, and may reduce the received signal-to-interference ratio. Additional processing of information on the network is required in order to treat the excess interference and trade off the conserved power for capacity advantage.

For a multihop network, capacity can be defined as the total rate by which information originated by all sources reaches the final destinations. Therefore, the techniques and strategies for maximizing capacity must compromise between the total amount of information that can be carried through each link and the number of hops that the information must take to reach the destinations. This paper examines some of the techniques by which we can augment the capacity or enhance the system performance in multihop networks. We focus on a simple architecture and address the connectivity scenarios. Inherent fading and interference averaging effects make CDMA an attractive access scheme to achieve a high system capacity.

Code-division multiple access (CDMA) is a multiple access technique in which each user is given access to the entire channel all the time, with users separated by giving each a unique spreading code. CDMA is a form of spread spectrum. Spread-spectrum signal occupies a bandwidth much greater than that of the message signal it conveys. The core of spread spectrum is the use of noise-like carrier waves and the bandwidth is much wider than the required for simple point-to-point communication at the same data rate. R. C. Based on this definition, spread spectrum systems have existed in one form or another for a long time. In essence, the art of spread spectrum is seen in the way it spreads the signal energy onto a very wide bandwidth; transmits the expanded signal; and then, at the receiver, reconcentrates the energy back into the original bandwidth. As a result of this process, the signal can be transmitted at very low power levels with a minimum probability of detection and interception, and it can be very resistant to jamming and interference.



T : Transmit Mode
R : Receive Mode

	slot 1	slot 2	slot 3	slot 4
Router R3	R	T	R	T
Router R2	T	R	T	R
Router R1	R	T	R	T

A->B:
A transmits to B

slot 1	slot 2	slot 3	slot 4
T1->R1 T2->R3	R1->R2 R3->BS1	T1->R1 T2->R3 R2->R3	R1->R2 R3->BS1

Figure 2. Packet relaying in upstream, assuming terminals T1 and T2 always have some packets to transmit. In each time slot, the neighboring routers are in different modes in order to be able to exchange data.

The upstream and downstream transmissions may involve multiple routers in which packets are relayed in the same frequency band using a time division duplex (TDD) scheme (see figure 2). TDD is explained in figure 2a.

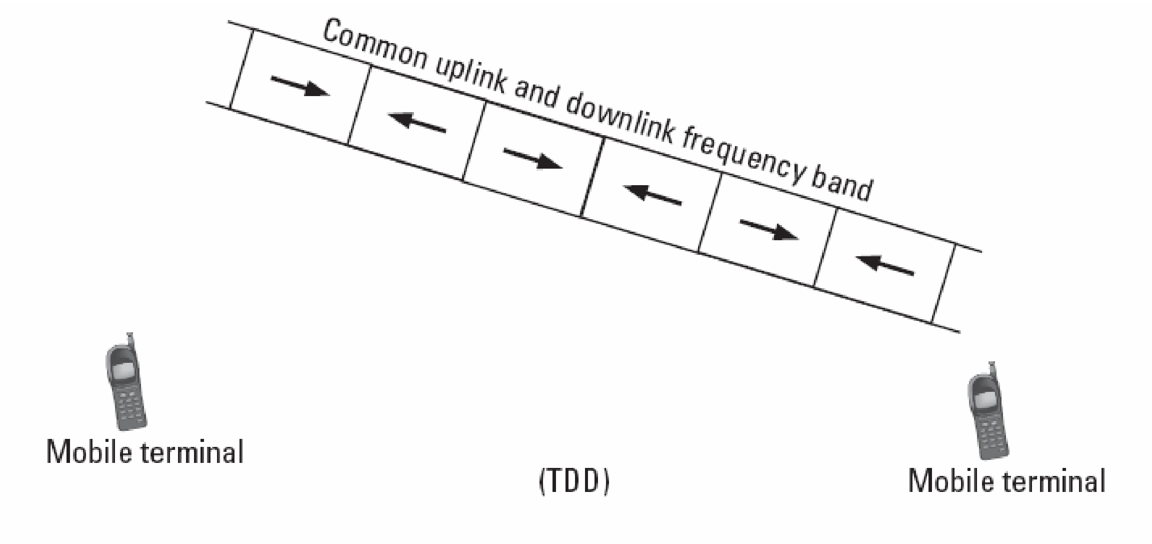


Figure 2a.

Time-division duplex (TDD) refers to duplexes communications links where the uplink is separated from the downlink by the allocation of different time slots in the same frequency band.

In each frequency band and in each time slot, packets are transmitted using different spreading sequences. Note that due to high power level difference between transmit and receive signals, simultaneous transmission and reception in the same frequency band is not practical. All nodes are required to be synchronized in order to reduce packet collision. Practically, however, exact synchronization is only necessary within the range of a few hops. Terminals and routers may send and receive on several spreading sequences, dynamically assigned by base stations. Base stations instruct the nodes which channels to listen to and on which channels to transmit their data. In each slot, almost half of all the routers are in transmit mode and the rest are in receive mode. The routers change their mode alternately at the end of each slot; hence other nodes know when they can transmit packets to them. Efficient use of routers leads to a reduction in the required transmits power, thereby providing an opportunity to extend the cell size or to allow higher data rate. It further helps in better scheduling of traffic. For example, bursty traffic can be handled through a route without affecting the reception capability of the other parts of the network. In the following sections, we show how the network can take advantage of this power saving to support higher data rate traffic. Realizing the full potential of the allocated bandwidth will require taking advantage of all of the new proposals for coding and space-time processing for radio links. In a multi-user system, link capacity can also be increased by techniques like interference cancellation and multiuser detection. As more information on the whole network is available, medium access techniques and routing strategies can highly increase the total capacity.

2. Link capacity in single user system

The Shannon limit or Shannon capacity of a communication channel refers to the maximum rate of error-free data that can theoretically be transferred over the link if the link is subject to random data transmission errors. The Shannon limit is a statement of Shannon's theorem for the case of a limited bandwidth communication channel.

The Shannon limit states the following: For an analog channel of signal strength *S* which is subject to interference by a Gaussian white noise interference signal of strength *N*, the best possible information transfer rate *C* achievable by even the most clever error correction scheme will be:

$$C = W\log_2(1 + S / N)$$

where

C = net channel capacity (in bits per second) after error correction,
W = raw channel frequency or bandwidth,
S/N = signal-to-noise ratio given as a straight ratio (not in decibels)

Shannon capacity theorem thus gives the maximum spectral efficiency in terms of bits-per-second per-Hertz and it depends on channel statistical behavior as well as design aspects such as power control strategy and receiver technology. A simple case is if there is a single transmit and a single receive antenna in a flat fading channel with an average-power constraint and perfect channel state information (CSI) available both to transmitter and receiver. It has been shown in that the optimal transmit power assignment, *P*T, satisfies:

$$P_{\mathrm{T}}(\gamma) = \begin{cases} \dfrac{1}{\gamma_0} - \dfrac{1}{\gamma}, & \gamma \geqslant \gamma_0, \\ 0, & \gamma < \gamma_0, \end{cases} \qquad (1)$$

Where • is the fading coefficient normalized by noise power and the constant •0 is determined by the average power constraint and the specific distribution of •

Link capacity is increased when the rest of the network is limited to the average received interference. In direct sequence spread spectrum modulation, this interference is well modeled by a normal distribution. Connections among routers and base stations using highly efficient links have a direct effect on increasing the total capacity of cellular structure. As interference due to relaying packets is reduced, routers act like stand-alone base stations, and system capacity is increased proportional to the ratio of routers to base stations.

2.1. Diversity techniques

Multipath fading severely attenuates the transmitted signal; it also provides several replicas of the signal at the receiver. These replications can be used at the receiver by optimally separating and combining the total received power. Multipath is simply a term used to describe the multiple paths a radio wave may follow between transmitter and receiver. Radio waves that are received in phase reinforce each other and produce a stronger signal at the receiving site, while those that are received out of phase produce a weak or fading signal. Multipath fading may minimized by using frequency diversity or space diversity. Frequency diversity refers to the use of complementary radar transmissions or multiple radar systems operating cooperatively at different frequencies. Frequency diversity normally relates to multiple radar sites coordinated in such a way as to achieve the frequency management task. Frequency diversity forces the jammer into an undesirable bandwidth situation. Space diversity is a method of transmission or reception or both, in which the effects of fading are minimized by the simultaneous use of two or more physically separated antennas, ideally separated by one more wavelengths. By increasing diversity order, distribution of fading tends to follow a Gaussian distribution with higher capacity limit.

In multihop networks, a receiver can benefit from one other diversity domain which is obtained from receiving several replicas of the same packet in different time slots and transmitted or relayed from different nodes. Therefore, it gives rise to both diversity gain and coding gain. This diversity method can also highly reduce interference and increase system capacity.

2.2. Multiple-in multiple-out radio links

In bandwidth limited wireless channels, high data rate transmission requires a highly spectral efficient code which is impossible. We can increase the number of channels between the transmitter and receiver pair by using more antenna elements at each site to get high data rate

If there are nR receive and nT transmit antennas in a flat slowly fading environment, the channel can be described by a *(*nR, nT*)* matrix H whose ij th element gives the propagation loss from the j th transmit antenna to the ith receive antenna. Let P0 and Pn denote the transmit signal power and average power , respectively. When perfect CSI is available at the receiver, Shannon capacity as a random variable can be given as:

$$C = \log_2 \det\left[I_{n_\mathrm{R}} + H H^\mathrm{T} \frac{P_0}{n_\mathrm{T} P_n} \right], \qquad (2)$$

.

where InR is the nR×nR identity matrix. For a large number of antenna elements, capacity increases linearly, rather than logarithmically, with increasing signal-to-noise ratio (SNR). Consider the case of one transmits and multiple receive antennas. For this case, equation (2) simplifies to:

$$C = \log_2\left[1 + \frac{P_0}{P_n}\sum_{i=0}^{n\mathrm{R}} |H_i|^2\right]. \qquad (3)$$

This capacity can be achieved by multiplying the input SNR by the antenna gain when array weight vector • = *(*• 1,• 2*, . . . ,*• *n*R *)* is defined as • 1*Hi* = • *iH*1 for all *i*.

By increasing the number of channels, by providing temporal, transmit, and receive diversity the capacity in multiple-in multiple-out radio links is thus increased.

2.3. Space-time coding

A solution to achieving improved capacities is to employ multiple antennas at the transmitter and receiver of the wireless system. Space time coding(STC) deals with the design of good codes for multiple antenna wireless systems. Traditionally there are two scenarios of interest which are *noncoherent* and *coherent* STC. In *noncoherent STC* neither the receiver nor the transmitter knows the channel propagation coefficients, while in *coherent STC*, only the receiver has knowledge of channel through training. The basic the problem in STC is to design codes with simple encoding and decoding algorithms. In Coherent Space-Time Codes, Knowledge of the channel state information (CSI) at the receiver simplifies the coding. IN Differential and Noncoherent Space-Time Codes, We use differential detection methods for multiple antenna systems. This gives rise to unitary differential STC. Differential STC is well suited for slowly varying channels and the receiver does not require channel knowledge or the statistics of the propagation coefficients.

Space time coding is an effective transmit diversity technique to combat fading in wireless communication. Space time codes are a highly bandwidth-efficient approach to signaling that takes the advantage of the spatial dimension by transmitting a number of data streams using multiple collocated antennas. In practice, uncorrelated diversity branches can be obtained at the mobile by spacing the antenna elements approximately one-half wavelength (•c) apart.

3. Link capacity in multiple user system

We consider the case that more information on other users such as spreading codes and directions of arrivals (DOA) is available to the receiver and discuss its effect on link capacity.

3.1. Multiuser detection

Wireless communication systems are required to accommodate many users simultaneously, while providing high data rates and on-demand data transfers. The multiuser communication system consists of many users attempting to communicate with a single receiver over a common set of channel resources. Though simple, this model captures the basic architecture of most modern cellular communication systems deployed throughout the world. Modern communication systems provide multiple access through a combination of three methods: time-division (TDMA), frequency division (FDMA), and code-division multiple access (CDMA). TDMA and FDMA techniques essentially divide the time and frequency resources respectively between the users. CDMA, on the other hand, allows all users to use both time and frequency resources simultaneously.

In CDMA communications, the users are multiplexed by distinct code waveforms, rather than by orthogonal frequency bands, as in frequency-division multiple-access (FDMA), or by orthogonal time slots, as in time-division multiple-access (TDMA). Two major factors that limit the performance of CDMA systems are multiple-access interference (MAI) and multipath channel distortion. Many advanced signal processing techniques have been proposed to combat interference and multipath channel distortion, and these techniques fall largely into two categories: *multiuser detection* and *space-time processing*

Multiuser detection techniques exploit the underlying structure induced by the spreading waveforms of the CDMA user signals for interference suppression. Various linear and nonlinear multiuser detectors have been developed over the past decade. It has been well established that multiuser detection techniques can substantially enhance the receiver performance and increase the capacity of CDMA communication systems. More recently, adaptive multiuser detection has received considerable attention. Adaptivity not only allows multiuser detection to be applied without additional protocol overhead with respect to that required by conventional methods, but it also allows multiuser detectors to operate in the dynamic environments found in mobile communications applications.

If *K* users in a flat slowly fading environment are simultaneously transmitting to a receiver, the channel can be described by *K* random variables •*i* modeling the propagation loss from the *i*th user to the receiver. When the receiver has perfect CSI and the transmit power of each user is *Pi*, the maximum achievable capacity for all users is found to be

$$C = \log_2\left[1 + \frac{\sum_{i=0}^{K} P_i \nu_i}{P_n}\right]. \qquad (4)$$

For a large number of users, this formula is simplified to:

$$C = \log_2\left[1 + \frac{K P_{\text{av}}}{P_n}\right], \qquad (5)$$

Where *P*av denotes the average transmitted power per user.

In asynchronous CDMA, each user transmits on all available dimensions, creating interference for other users. In second generation CDMA systems, this interference is considered as noise, resulting in a performance degradation as more users become active in the network. Multiuser detection is a method to obtain the achievable capacity as the co channel interference increases by receiving more packets from other users. Equation (4) also shows that by increasing the number of transmitted packets, the maximum information that each packet can bear is reduced. One effective method to overcome this problem is to use methods like hybrid automatic repeat request where packets are saved at the destination and more parity bits are requested by the receiver until data is decoded. By this method, multirate traffic is generated with the rate changing adaptively based on channel state.

Multiuser detection has the capability of reducing sensitivity of decoding to the near-far effect and power control which results in a lower bit error rate in the upstream and in high power conservation in the downstream since varying transmit power may be used for near and far users. Multi-user detection is an effective technique that can remove the saturation region of capacity versus SNR, and therefore it has the potential to take advantage of the conserved power in multihop networking to increase capacity.

3.2. Smart antennas and interference cancellation

A smart antenna system combines multiple antenna elements with a signal processing capability to optimize its radiation and/or reception pattern automatically in response to the signal environment. Smart antenna solutions are required as the number of users, interference, and propagation complexity grows. In truth, antennas are not smart—antenna systems are smart. Generally co-located with a base station, a smart antenna system combines an antenna array with a digital signal-processing capability to transmit and receive in an adaptive, spatially sensitive manner. In other words, such a system can automatically change the directionality of its radiation patterns in response to its signal environment. This can dramatically increase the performance characteristics (such as capacity) of a wireless system. The following are distinctions between the two major categories of smart antennas regarding the choices in transmit strategy:

- switched beam—a finite number of fixed, predefined patterns or combining strategies (sectors)
- adaptive array—an infinite number of patterns (scenario-based) that are adjusted in real time

A simple antenna works for a simple RF environment. Smart antenna solutions are required as the number of users, interference, and propagation complexity grow. Their smarts reside in their digital signal-processing facilities.

Like most modern advances in electronics today, the digital format for manipulating the RF data offers numerous advantages in terms of accuracy and flexibility of operation. Speech starts and ends as analog information. Along the way, however, smart antenna systems capture, convert, and modulate analog signals for transmission as digital signals and reconvert them to analog information on the other end.

In adaptive antenna systems, this fundamental signal-processing capability is augmented by advanced techniques (algorithms) that are applied to control operation in the presence of complicated combinations of operating conditions.

Link capacity will not linearly increase by the number of transmitted packets with multiuser detection. For high SNR, splitting power on different channels results in a better performance. Due to imperfections in practical antennas, the reliability of reception from terminals located in the areas where adjacent sectors overlap is degraded significantly. Using directional antennas at terminals and routers is not effective, since due to wide angular spread of the signal, receive antennas cannot distinguish between the directions of signal arrivals from different transmitters. An M-element smart antenna [6], however, can null M • 1 interferers independent of the multipath environment. By adding routers to the cellular structure, as the number of nodes communicating to any node is reduced, smart antennas can be more effective. In this structure, even array antennas with fixed patterns are performing better since beam separation needed for transmission can be accomplished more easily.

4. Network capacity

Till now we have discussed the methods to increase the capacity of these that the maximum information can be transferred through the network links. But we have problems with the randomly varying nature of the transmission medium and d we considered how to achieve a reliable link when there is interference. In our multihop packet CDMA network, we are only concerned with time and space allocation. Time scheduling is referred to as medium access protocol and space sharing is referred to as routing strategy. We consider within the network, the packet end-to-end quality of service is an important parameter. Information exchange between nodes is useful only if it directs the information toward the destinations.

So to obtain optimal transmission strategy including transmit power adjustment, time scheduling, and routing is not simple for radio networks because different packet types bear different amounts of information and need different SNRs to be detected. QoS requirements like minimum acceptable bandwidth and maximum delay add other constraints to the system that affect the capacity calculation. Just like the single channel case where capacity is a function of CSI, feeding back system state information (SSI) to the transmitting nodes has a direct effect on the choice of adjustable parameters such as transmission power and data rate to achieve the capacity limits. In a multihop wireless network, medium access technique and routing strategy are closely correlated. When transmission is destined to a very close neighbor, there is no need for strict. On the other hand, if transmission is directed toward a region with many receiving nodes, slot assignment can significantly reduce the interference level and result in a better performance.

Routing has a significant impact on the network capacity. Routing helps to establish a multihop link between any two nodes of the network. Routing provides two functions: first, to increase the number of available channels in the space, the transmit power and next hop are assigned for each node and second, directing the traffic with a fewer number of hops so that to make more information available towards the destination. For any system structure based on a transmit power constraint and propagation loss, not all nodes can be connected to each other. Although transmission on short hops reduces the interference, at the same time the network traffic is artificially increased due to several transmissions of the same packet by intermediate hops. Consequently, the optimum strategy must include the excess power consumed due to relaying of packets.

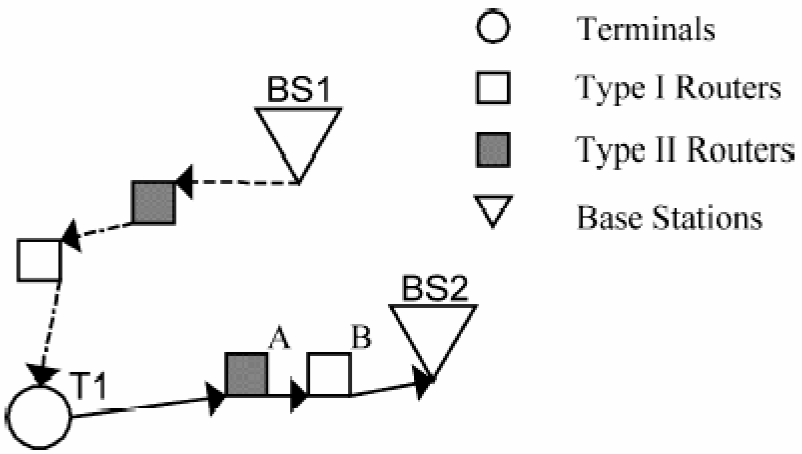


Figure 3. Transmission in the downstream from BS2 to T1 is not a good choice since transmitting packets from A to T1 creates high interference for the very close router B.

The strategy of minimizing energy is far from optimum for maximizing capacity. Figure 3. shows a structure with asymmetric links and loop-free connections. In each slot, we have categorized all the routers which are in the same mode as routers of type I and routers of type II. Since transmission in the forward and backward direction in the link might create different interference levels on the neighboring receivers, some of the links are used as they are asymmetric. Nodes A and B are the nearest neighbors to each other. In the downstream, packets received from B to A cannot be relayed to the terminal, since due to high distance ratio from router A to terminal, and router A to router B. This transmission creates a very high interference at node B. So a better choice is to transmit the terminal's packets from a different base station and through a different path. But, if multiuser projection receivers are used in the physical layers, receivers can remove the high interference from the close neighbors, and therefore, the same path can still be used for the downstream transmission. So to maximize network capacity, the routing strategy must be specifically designed for this purpose, and it must be a function of the techniques used in the physical layer.

The optimum solution given for this problem is a strategy which jointly designs techniques and algorithms for physical, data link, and network layers. This strategy determines the following decision variables:

- The techniques and technologies to be used in receivers and transmitters
- To whom the transmission should be addressed
- The amount of information to be transmitted on each channel
- The transmit power level

In [4], the authors have derived algorithms for power control in a conventional cellular network in which an array of modes (transmit power level, modulation method) is selected based upon the current state of the system. The algorithm is based on minimizing the average cost until the buffer of the node empties. This approach, appropriately formulated to include relevant dynamic system variables, may load-balance an overlaid ad hoc network by minimizing the total path cost. This, in turn, yields higher throughput.

This optimum strategy has been analyzed in [5]. The strategy is based on minimizing an objective function on a slot by slot basis. Minimizing this function will give us the next hop, transmit power level, and the amount of information in bits to transmit. In each time slot, we define a cumulative cost for each node with the following components:

- Overhead cost, a function of the Shannon capacity with arguments of transmit power and aggregate interference at the receiver
- transmit power cost
- Next hop cost, the cost associated with the neighboring node with minimum cumulative cost

The neighboring node for which the cost is minimized is chosen as the next hop in the path, and this process is repeated for each time slot. This algorithm is clearly dynamic and is expected to converge to an optimal solution after a small number of time slots.

5. System performance

In this section we describe how the performance is improved when previously stated techniques are deployed. We assume a following scenario for routing. A transmitter sends data to a receiver for which the link propagation loss is minimum as compared to other links. We also assume that ideal power control is employed, and the required received power levels at all receivers are the same. Terminals transmit data with probability ‘pt’ independently from slot to slot. Different types of network nodes are distributed uniformly in the plane with different per-unit-area densities.

We give the probability density function (pdf) of the received power per packet at each node, Hi. Let •Rx be the density of receivers, including routers in receive mode, and let m be the propagation exponent. The probability density function(pdf) of the received power for a node in the center of a circular region, Ra, with radius a due to transmission of one packet within this region has been derived in [13] as:

$$f_{H_i}(h) \approx \frac{2}{mNh^{(1+2/m)}} + \frac{1}{N}\delta(h-1) \qquad (6)$$

in which N = •Rx•a2, •(·) is the Dirac delta function. Each receiver, based on whether a transmission is destined to that receiver or not we use the terms intracell and intercell interference. By this definition, the first term in formula 6 contributes to the total intercell interference and the second term to intracell interference. The moments of Hi in the limit as N • • are obtained as:

$$\lim_{N\to\infty} N \int_0^1 h^k f_{H_i}(h)\,\mathrm{d}h = 1 + \frac{1}{mk/2-1} \quad \text{for } k \geqslant 1 \text{ and } m > 2. \tag{7}$$

The simulation results have shown that the received power from different nodes is nearly independent of each other. Therefore, the characteristic function of the total received power can be obtained from the characteristic function of the received power due to individual nodes when *an* approaches infinity. The complete discussion for calculating the pdf of the received power from each node considering the effect of the traffic density has been given in [14]. For the simple case that all the transceivers are of the same type, transmitting maximum of one packet in each slot, and links efficiencies are equal, the pdf of the total received power at each receiver, *H*T, can be obtained as:

$$\begin{aligned} M(\omega) &= E\left(\mathrm{e}^{-\mathrm{i}\omega H_{\mathrm{T}}}\right) \\ &= \exp\left(-\frac{\lambda_{\mathrm{Tx}}}{\lambda_{\mathrm{Rx}}} \sum_{k=1}^{\infty} \frac{(\mathrm{i}\omega)^k}{k!}\left(1 + \frac{1}{(mk/2-1)}\right)\right) \end{aligned} \tag{8}$$

in which •Tx is the density of packets in the network. The pdf can easily be obtained by calculating the inverse fast Fourier transform of this characteristic function. It is interesting to note that for *m* = 4, this function can be expressed based on the error function, where fast numerical algorithms for its calculation exist:

$$M(\omega) = \exp\left(-\frac{\lambda_{\mathrm{Tx}}}{\lambda_{\mathrm{Rx}}}\sqrt{\mathrm{i}\pi\omega}\,\mathrm{erf}\left(\sqrt{\mathrm{i}\omega}\right)\right). \tag{9}$$

In the first example, we consider the case where the system is using interference-limited receivers with multiuser detection capability of *K*c = 50, and examine the outage probability as a function of the average number of packets generated by terminals in each slot. Figure 4 shows the effect of increasing the density of routers when highly efficient links are established among routers and base stations. • is the efficiency factor and is defined as the efficiency ratio of links among the routers and base stations to links with terminals connected at one end. Due to randomness in the locations of routers and also variance in the number of packets which routers relay, when • = 1, increasing the density of routers, •R, increases the interference variance and thus de creases the system throughput. In other words, when all the network links have the same capacity, in our simple routing scenario, power conservation does not result in better performance. As • increases, higher density of routers results in better performance. It is seen from the figure that for outage probability of 10• 2 and efficiency factor of • = 10, increasing the density of routers from 0 to 10 will result in 300% throughput increase.

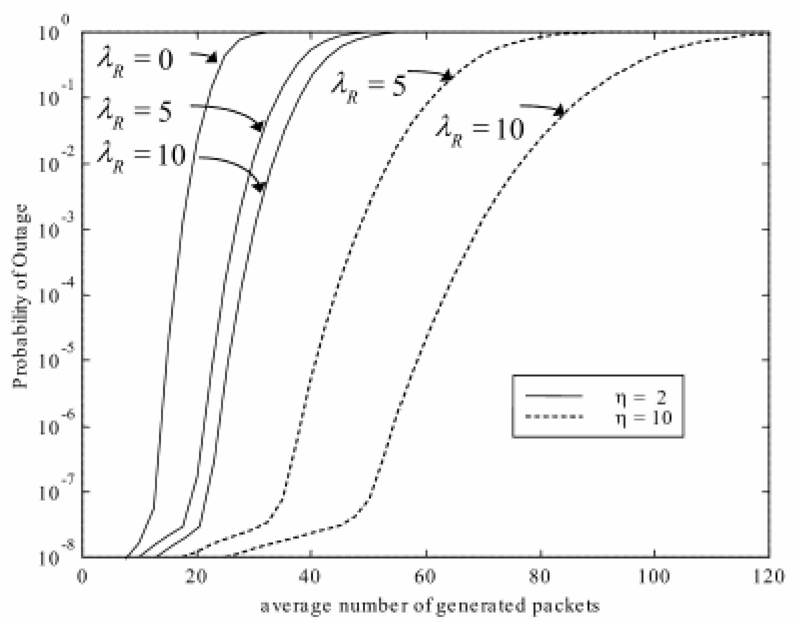


Figure 4. Probability of outage versus the average number of generated packets for different density of routers $\lambda_R = 0, 5, 10$ and different link efficiencies, η, for connections among routers and base stations. Density of base stations is $\lambda_{BS} = 1$ and receivers are interference limited with multiuser detection capability $K_c = 50$.

In the next example the effect of diversity techniques and multiuser detection on performance are considered. Each base station receives several times the information of a packet as the packet relays by routers before it reaches the destination. For nodes located at the border of selection regions, originated packets and their replicas, relayed by routers, are both received at the base station with high power. When the packet is finally destined to the base station, it uses all the previously received replicas to decode the data. After decoding the packet, this information can now be used for removing the corresponding interference from the received signal in previous slots. As seen in figure 5, the effect of using these techniques is a multifold increase in system capacity as the conserved power is being optimally used.

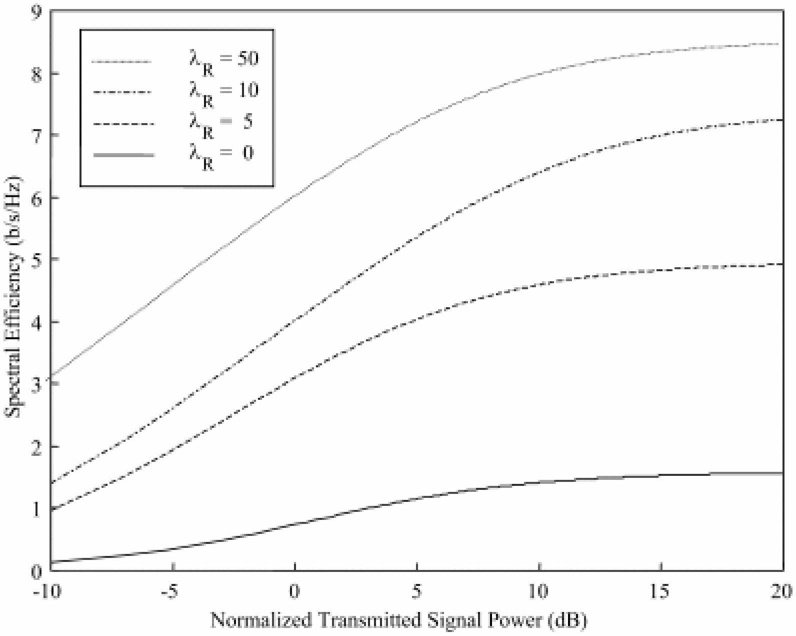


Figure 5. Spectral efficiency as a function of transmitted power for density of routers $\lambda_R = 0, 5, 10, 50$, density of terminals $\lambda_T = 50$, density of base stations $\lambda_{BS} = 1$.

6. Conclusion

In this paper we have shown that wireless multihop networks overlaid with cellular structure have the potential to support high data rate Internet traffic. First, we explained the methods for increasing link capacity in single-user systems then we consider a different set of techniques suitable for multi-user systems. Communication between two hosts in this type networks is not always direct- it can proceed in a multihop fashion so that every host is also a router. There's is no need of infrastructure. Each node is equipped with one or more radios. Each node is free to move about while communicating. Paths between nodes can be multi-hop. In single-hop networks the data packets are transmitted from source to destination in one hop without using intermediate nodes. In a multihop network no node is distinct from the other and data transmission to remote stations is possible via several hops. Terminals in this type of network mainly rely on short life-time batteries, and therefore, energy conservation is a critical design criterion. For a multihop network, capacity can be defined as the total rate by which information originated by all sources reaches the final destinations. Therefore, the techniques and strategies for maximizing capacity must compromise between the total amount of information that can be carried through each link and the number of hops that the information must take to reach the destinations. This paper examined some of the techniques by which we can augment the capacity or enhance the system performance in multihop networks. The architecture considered in this paper benefits from inexpensive routers in the cellular structure to achieve the target capacity obtained by the cell splitting technique. By a suitable routing strategy, total transmitted power is highly decreased in multihop transmission. However, power conservation may not necessarily result in higher capacity since SIR is not affected by scaling transmitted power of all nodes. Diversity, multi-element arrays, and space-time coding were discussed as techniques that could reduce the interference due to packet relaying. We also discussed multiuser detection and smart antenna techniques to further reduce the interference by better channelization of space and benefiting from information available on interference. Some of the techniques reviewed here have already been implemented as enhancements to existing cellular networks and are of practical interest. We further addressed some of the many new challenges that were encountered in optimizing the capacity of this structure. We have seen several illustrations of how different combinations of such techniques yield a multifold increase in system capacity. With the feasibility of increasingly sophisticated wireless devices, multihop networking promises widely-spread networks with high data rate support.

References:

[1]http://cec.wustl.edu/~cs333/calendar/Mobile_Computing_in_Ad_hoc_Wireless_Networks.ppt
[2] On energy efficiency and network connectivity of mobile adhoc networks by Wing o Yuen and Chi Wan Sung
[3] G.J. Foschini, Layered space-time architecture for wireless communication in a fading environment when using multi-element antennas, Bell Labs Tech. J. (Autumn 1996) 41– 59.
[4] S. Kandukuri and N. Bambos, Multimodal dynamic multiple access (MDMA) in wireless packet networks, in: IEEE Infocom2001 (2001) pp. 199–208.
[5] C.A. St. Jean, A.N. Zadeh and B. Jabbari, Combined routing, channel scheduling and power control in packet radio ad hoc networks with cellular overlay, in: Proc. IEEE VTC’2002-Spring (2002), to appear.
[6] J.H. Winters, Smart antennas for wireless systems, IEEE Personal Comm. (February 1998) 23–27.
[7] An Overview of Mobile Adhoc Networking, M. Scott Corson, Clarion Technologies, Bedminister, NJ.
[8] A scalable workbench for implementing and evaluating distributed applications in mobile ad-hoc networks
[9] http://www.comnets.rwth-aachen.de/report/subsubsection2_4_6_7_1.html
[10]Multihop packet Scheduling in WDM/TDM Networks with Nonnegligible Transceiver Tuning Times
[11] Mobile Infostation Networks and Multihop Networks, Roy D.Yates
[12] On energy efficiency and network connectivity of mobile ad hoc networks, Wing Ho Yuen, Chi Wan Sung
[13] Adhoc Networks , Jie Wu, Ivan Stojmenovic
[14] A performance Comparison of Multi-Hop Wireless Ad Hoc Network Routing Protocols, Josh Broch, David A. Maltz, David B. Johnson, Yien-Chun Hu, Jetcheva
[15] Topology Control and Routing in Adhoc Networks: A Survey, Rajmohan Rajaraman