ON THE RELAYING CAPABILITY OF THE RECONFIGURABLE WIRELESS NETWORKS

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ABSTRACT: In this paper, we evaluate the performance of an ad-hoc network architecture, investigating the effect of various design and operational parameters on the blocking and dropping probabilities. In particular, we study the improvement in the network coverage due to the multi-hop routing feature. Furthermore, the effect of limiting the path length on the network performance is studied, showing that there is an optimal value for this parameter.

INTRODUCTION

Reconfigurable Wireless Networks (RWN) are ad-hoc wireless networks [1] whose topology is continuously changing, self-adapting to the connectivity and propagation conditions and to the traffic and mobility patterns. The main application of the RWN is in situations where a network needs to be rapidly deployed without prior planning and that needs to provide reliable and uninterruptible communication in harsh propagation conditions. Furthermore, the network needs to support high degree of survivability; failure of a single or co-located entities should have, ideally, no effect on the performance of the rest of the network. Possible examples of the use of the RWN are for tactical military communication, for disaster recovery operation, and for ad-hoc commercial installations, such as exhibitions. In particular, in tactical military applications, nodes in the RWN can be trucks, tanks, airplanes, ships, soldiers, etc.

In the conventional wireless cellular networks, mobiles communicate only with their assigned base station; i.e., there is no direct **peer-to-peer** communication. Any mobile's transmission, even directed at another mobile in the same cell, is always relayed through the cell's base station. In contrast, in the RWN, the regular mode of operation is by direct mobile-to-mobile communication. Mobiles that cannot be reached directly, use other mobiles to route (relay) their messages; i.e., using **multi-hop** routing. In this paper, we are interested in evaluating the performance of these type of networks under some network, traffic, and mobility models.

NETWORK, TRAFFIC, AND MOBILITY MODELS

The coverage area of our network is a 10 miles X 10 miles grid, with initial random distribution of mobiles throughout this area. To simulate radio propagation obstructions, there are randomly distributed areas, called dark territories. There is no communication between two mobiles, if a line connecting the two mobiles passes through a dark territory.

Each node is equipped with a transmitter/receiver pair, operating in half-duplex mode. We assume here a narrowband system, in which the total spectrum is divided into channels through the FDM/TDMA technique. To make sure that the blocking is not spectrum-limited, we assumed a large enough number of frequency channels. The number of slots per TDMA frame is, however, a parameter in our simulation. Because of the half-duplex nature of transmission, each mobile can establish $\lfloor n/2 \rfloor$ simultaneous links, when the frame is of n slots. This means that a mobile can relay traffic of up to $\lfloor n/4 \rfloor$ other mobiles, if no local traffic is to be communicated and up to $\left\lfloor (n-2)/4 \right\rfloor$, if local traffic exists.

We assume that the maximum transmission power of a mobile limits its connectivity to a radius of $r_{\max}$. Any mobiles that can be reached by a mobile in question are referred to as the mobile's neighbors.

Mobiles request communication with other mobiles in a random manner. The interarrival time between two connection requests and the length of a connection are modeled as negative exponential with parameter λ^{-1} sec/call and μ^{-1}, respectively. Calls destined to busy destination are cleared. Also, busy mobiles do not generate new calls. Thus, there is no queueing in the system.

A call is *blocked* if, there is neither a direct link, nor there exists a relaying path with enough capacity between the source and the destination. Cleared calls are not counted as blocked calls, as to account only for the limitations due to the network relaying capacity. A call can be *dropped,* because of two reasons: if due to mobility a relaying or a direct path is broken (due to too large distance between the nodes or due to a propagation obstruction), or a local connection request arrives to one of the relaying nodes that does not have any capacity left (priority is given to local traffic), and, in both cases, there is no possibility of reestablishing the connection through a different path.

Mobiles roam freely throughout the coverage area, but their movement is restricted by the size and shape of the area. At any point in time, mobile movement is characterized by two parameters, its velocity, $\vec{v}$,

(value, ν, and direction ϕ) and its current position, *(x,y)*. The velocity is updated every time interval, Δt, according to the following formula:

$$\nu(t+\Delta t) = \min[\max(\nu(t)+\Delta\nu, 0), \nu_{\max}],$$

where $\Delta\nu$ is a uniformly distributed random variable in $[-\alpha \cdot \Delta t, \alpha \cdot \Delta t]$, $\nu_{\max}$ is maximal mobile velocity, and α is the maximal node acceleration/deceleration (assumed here to be of equal magnitude). The movement direction, ϕ, is also updated every Δt:

$$\phi(t+\Delta t) = \phi(t) + \Delta\phi,$$

where $\Delta\phi$ is a uniformly distributed random variable in $[-\Delta\phi_{\max} \cdot \Delta t, \Delta\phi_{\max} \cdot \Delta t]$, and $\Delta\phi_{\max}$ represents the maximal angle change per unit time. This mobility model is an improvement on the previously used in the literature Brownian Motion model. Initial velocity $\vec{v}$ of the mobiles is assumed random, within the above-mentioned constraints.

MAC-layer connections are established between neighbors [2]. With time, the mobiles can become separated by large enough distance or by an obstacle, so that connections are broken. Likewise, mobiles may migrate close enough to each other to become neighbors and to establish connection.

THE SIMULATION

We use an event-driven simulation to determine the effect of different parameter setting on the performance of the network. In particular, we evaluate the average system blocking and dropping probabilities as a function of: number of mobile in the system (M), max transmission radius ($r_{\max}$), max number of hops in a relaying path (l), maximal angular change rate ($\Delta\phi_{\max}$), maximal velocity ($\nu_{\max}$), size of the coverage area ($S \times S$), number of slots per frame (n), and the average call duration (μ^{-1}).

Upon arrival of a call, the system first checks to see if the destination is busy. If it is, the call request is cleared, and a new call request is scheduled for the future. If the destination is not busy, the excess capacity of the source and destination is checked. (Excess capacity is the number of time-slots that are not currently being used by a mobile, where 2 slots are used for a local traffic and 4 slots for a relayed call.) If there is enough capacity for local traffic at the source and at the destination, an attempt is made to connect the source and the destination directly. The conditions for a direct connection are 1) the distance between the two mobiles of less than the transmission radius and 2) a path between the two mobiles that is not obstructed by a dark territory. If a direct connection is established, the excess capacity of each mobile is reduced and a call termination event is scheduled for the future.

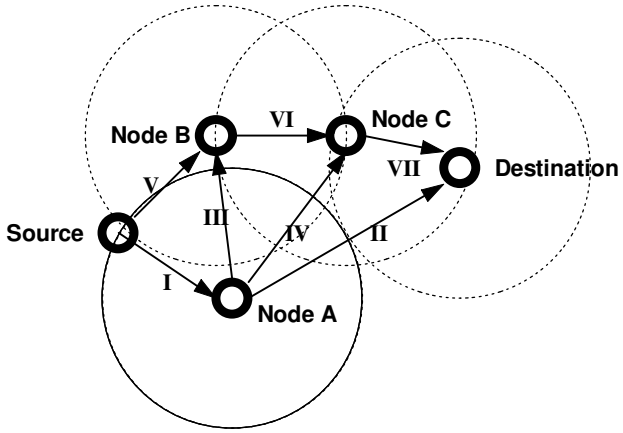

Figure 1: Example of a connection establishment

If a direct connection is not possible, a relaying path is attempted. Neighbors are checked for the possibility of carrying the connection. The conditions for relaying are the same as that for a direct connection, except that the relay node must also have at least 4 time-slots of excess capacity. The first mobile to meet the relay criteria is chosen. The relay reduces its excess capacity by 4 time-slots. If this relay can complete the connection itself, the connection is considered successful, the source and destination reduce their capacity by 2 time-slots and a call termination event is scheduled in the future.

If the relay cannot reach the destination directly, it attempts to relay through its neighbors. The process is the same as in the case of the first relay. The formation of the path will continue until the destination is reachable by one of the intermediate relays or the maximum path length is exceeded. In the latter case, the process will step back and try to establish the path through yet unchecked nodes. Thus, only when the whole "tree" that originates at the source is checked without being able to reach the destination, the process is terminated and the call is declared blocked. A new call arrival is scheduled for the source in the future. Note that if a connection is established, it may not be the shortest path. However, a reconfiguration will not take place until an event occurs that forces rerouting of the call (e.g., loss of a neighbor). Other routing protocols that overcome some of these shortcomings are possible [3] - [6].

An example of a call establishment is shown in Figure 1. The Source node, unable to connect directly to the Destination, tries Node A as a relay (I). Node A, also unable to reach the Destination directly (II), cannot continue, as other nodes are too far (III and IV). The Source proceeds with Node B as its relay (V), which is also unable to reach the Destination directly

and uses Node C as its relay (VI). Finally, Node C establishes a direct connection with the Destination, completing the path.

NUMERICAL RESULTS

Our simulation was tested for the range of parameters, as shown in the following Table:

Parameter	Sym-bol	Value or Range (Default Value)
Coverage area	$S \times S$	10 mi. X 10 mi.
Number of mobiles	M	51 mobiles
Time increment	Δt	2 sec
Maximal transmission radius	$r_{\max}$	3 mi. - 5 mi. (4 mi.)
Number of slots per frame	n	4 slots - 12 slots (8 slots)
Maximum number of hops	l	0 hops - 5 hops (3 hops)
Max angular change	$\Delta\phi_{\max}$	$0.2 \cdot \pi$
Maximal velocity	$v_{\max}$	25 mph -100 mph (50 mph)
Acceleration/Deceleration	α	1.8 mph/sec
Average call duration	μ^{-1}	180 sec
Avg. call interarrival time	λ^{-1}	0.5 - 10 calls/sec

The results of the simulation runs are shown in Figures 2 - 9. Figure 2 and 3 show the effect of changing the maximum length of the path, on the blocking and the dropping probabilities, respectively. The curve "0 hops" refers to the case when only direct connections are allowed. As can be seen from Figure 2, there is an optimal maximum path length that minimizes the probability of blocking, which, in this case, is 3 hops. This optimum comes about due to the fact that increasing the maximum path length, on one hand, allows formation of more connections and, thus, reduced the chances of a connection being blocked. However, on the other hand, when the maximum path length is increased, a small fraction of the calls will use a larger portion of the relaying capacity, thus increasing blocking of other calls. The increase in the dropping probability results mainly from the fact that longer paths have more chances of being broken due to the mobility of the mobile nodes. Thus, to reduce dropping probability, the maximum path length should be set as small as possible, with the exception of zero-length path (direct connections only). Direct connections tend to be frequently broken due to mobiles moving out of the transmission range of their corresponding nodes. Thus, there is a tradeoff between optimizing the probability of blocking and the probability of dropping.

Figures 4 and 5 show the effect of sizing the mobiles' transmission radius. The shorter the radius, the less chances are that a path from the source to the destination will be found, and the probability of blocking increases. Similarly, the dropping probability increases due to the fact that as connections are broken (due to relays moving out of the range of their receivers), it is more probable to establish a call when the transmission radius is larger. The decrease in the blocking probability is non-linear with the transmission radius, achieving most of the improvement when the radius is small. One has to add that as the number of mobiles increases, the probability of blocking decreases, as there are more mobiles available to perform the relay function. Thus, to achieve some level of performance, the transmission radius should be adjusted based on the density of mobile nodes present in the network.

Varying the user mobility (Figures 6 and 7) has only a small effect on the probability of blocking, but a major effect on the probability of dropping. As the mobiles move faster, the chances of breaking a connection increase and so the chances of dropping the connection.

Finally, Figures 8 and 9 show the effect of increasing the number of time-slots per frame. Since the relaying capacity of a node increases with an increase in *n,* it is not surprising that the probabilities of blocking and dropping both decrease. However, our study shows that there is some value of *n,* beyond which any further increase does not yield significant reduction in the blocking and dropping probabilities.

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