FRAMEWORK FOR MAXIMUM SURVIVABILITY ROUTING FOR A MANET

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ABSTRACT

In this paper, we develop a framework for Maximum Survivability Routing (MSR) for wireless Mobile Ad hoc NETworks (MANET). The routing is aimed at preserving network connectivity by choosing routing paths according to the remaining battery life of nodes along the route. While the remaining battery power P_i *at node* i *is a well-defined parameter that can be easily measured, the remaining battery life* $t_i = P_i / r_i$ *depends on the unknown future power-draining rate* r_i*. Accurate prediction of these future power-draining rates* r_i *is crucial for good performance of the MSR. We present simulation results that demonstrate superior performance of MSR as compared to some other known routing protocols when the power-draining rate is quasi-stationary and consequently, can be easily estimated from the historical data. Future research will be concentrated on adaptation techniques for highly transient scenarios.*

INTRODUCTION

A MANET is an autonomous collection of mobile users (nodes) that communicate over relatively bandwidth-constrained wireless links. Each node is equipped with portable computing abilities and wireless receivers and transmitters using antennas that may be omni-directional, highly directional, or possibly steerable. Since the nodes are mobile, the network topology may change rapidly and unpredictably over time. The network is *decentralized*, where all network activity will be executed by the nodes themselves. The nodes must dynamically discover the topology of the network and possible routing paths to send messages from a given source to a destination.

A vital issue in network routing for MANETs is to conserve power while still achieving a high packet success rate, since the life of a network is directly dependent on the remaining power sources. In [1], M. Subbarao developed Minimum Power Routing (MPR); the main idea of MPR is to select the path between a given source and destination that will require the least amount of total power expended, while still maintaining an acceptable *signal-to-noise ratio* (SNR) at each receiver along the route. In [2], Wieselthier, Nguyen, and Ephremides addressed this problem in the context of wireless multicasting, and in [3], Pursley, Russell, and Wysocarski considered this problem in a frequency-hopping ad hoc network. These works concentrate on homogeneous MANETs.

MANETs are typically heterogeneous networks with various types of nodes coming together to form an ad-hoc network, i.e., different military units ranging from soldiers to tanks forming an ad-hoc network. Thus, nodes will have different packet generation rates, routing responsibilities, network activities, and power source capacities. Hence, the power usage per node will differ. For example, a centrally located node typically will experience more power expenditure per unit time, i.e., higher *power-draining rate*, than a node on the network periphery. Hence, nodes will have dissimilar remaining battery powers and power draining rates, thereby yielding a different *utility* for the battery power per node. This life of a network is directly related to the efficient management of each node's battery *utility*.

In this paper, we develop a framework for Maximum Survivability Routing (MSR) which incorporates the power-conscious concepts developed in [1] with the realistic limitation of battery *utility* per node. MSR is aimed at *preserving network connectivity* by choosing routing paths according to the remaining battery life of nodes along the route. We consider scenarios when the power-draining rate is quasi-stationary and consequently, can be easily estimated from the historical data. We present simulation results that demonstrate superior performance of MSR as compared to the Shortest Distance Routing (SDR) and Minimum Power Routing (MPR) protocols.

SYSTEM MODEL

Consider a transmitter communicating with a receiver at distance of d in a MANET. As the transmitted signal propagates to the receiver, it is subject to the effects of shadowing and multipath fading, and its power P decays with distance d as follows:

$$P_d / P_0 = KFd^{-h}, \qquad (1)$$

where K is a constant, F is a non-negative random attenuation for the effect of shadowing and fading, P_0 is the transmitter power, and h is the path loss exponent. At the receiver, the desired signal is corrupted by interference from other nodes in the network. We assume that nodes know the identity of all nodes in the network and the distances to their immediate neighbors, i.e., nodes that are within transmission range. Interfering nodes use the same modulation scheme as the transmitter and nodes can vary their transmit power up to a maximum power $P^{\max}$. We assume that the multiuser interference is a Gaussian random process. At the receiver, the decoder maintains an estimate of the average Signal-to-Interference Ratio.

We consider a heterogeneous MANET with N nodes having different initial power levels and traffic loads. Let (i, j) denote a link from node i and node j. The remaining battery power P_i at node i, $i \in \{1,\dots,N\}$ is a well-defined parameter that can be easily measured. However, remaining battery life $t_i = P_i / r_i$ depends on an unknown future *power-draining rate* r_i and consequently, is considered as a random variable. Let T_i be an estimate of the remaining battery life $t_i = P_i / r_i$, and $u_i = u(T_i)$ be the *utility* [4] of the battery power at node i. Let $R = (i, a, b, c, \dots, j)$ denote a route from i to j through intermediate nodes $a, b, c,$ etc., and Ω_{ij} denote the set of all possible routes between node i and node j. It is natural to assume that $u_i = u(T_i)$ is a decreasing function of the estimate T_i. The cost of using route R can be expressed as a function of the *utility* of each node along the path:

(2) $$C_R = f(u_i, i \in R),$$

where function $f(\cdot)$ should be chosen to reflect the specific purpose of the routing.

It is natural to select minimum cost routes among all feasible routes with given origin-destination. We assume that once the route is selected, each node transmits with just enough power to ensure that the transmission is received with an acceptable bit error rate Y. Threshold Y is a design parameter and may be selected according to the network performance desired. Let $(E_b / I_0)_{\min}$ be the bit energy-to-interference ratio necessary at a node to achieve acceptable bit error rate Y. It follows from (1) that the bit energy-to-interference ratio for transmission from node i to node j is

(3) $$(E_b / I_0)_{ij} = S_{ij} P_{ij} r_{ij}^{-h}$$

where factor S_{ij} characterizes the current channel conditions and interference on link $i \to j$, P_{ij} is the transmitter power used at node i to communicate with node j, and r_{ij} is the distance between node i and node j. Note that $S_{ij} \neq S_{ji}$ since the channel conditions may be not symmetric. With knowledge of the instantaneous factor S_{ij}, node i can determine the transmission power to node j necessary to achieve the bit energy-to-interference ratio $(E_b / I_0)_{\min}$ as follows:

(4) $$P_{ij} = \frac{(E_b / I_0)_{\min}}{S_{ij} r_{ij}^{-h}}$$

However, since the instantaneous factor S_{ij} fluctuates due to multiuser interference, we assume that transmission on link $i \to j$ achieves the bit energy-to-interference ratio $(E_b / I_0)_{\min}$ with the transmission power

(5) $$P_{ij} = \frac{(E_b / I_0)_{\min}}{\bar{S}_{ij} r_{ij}^{-h}}$$

where $\bar{S}_{ij}$ is, based on the historical data, estimate of the current S_{ij}.

MAXIMUM SURVIVABILITY ROUTING

Maximum Survivability Routing (MSR) is aimed at *preserving network connectivity* by choosing routing paths according to the remaining battery life of nodes along the route. If the aim of the network is to prolong connectivity for *every* node, then the routing should avoid transmitting through the node with the *least* remaining battery life. However, this routing "around" approach may require large *total* power expenditures due to an increase in the number of hops or distance between transmitting nodes. If the network can sacrifice connectivity for one or a small number of nodes, the connectivity for the remaining nodes may be significantly prolonged. The following *utility* function and cost function formulates this scenario:

(6) $$u_i = u(T_i) = 1/T_i,$$

(7) $$C_R \equiv f(u_i, i \in R) = (\sum_{i \in R} u_i^b)^{1/b},$$

where $b \geq 1$ is a parameter. In order to preserve the connectivity of the network, the minimum cost route (route with the longest life expectancy) between node i and node j is selected:

(8) $$R_{selected} = \arg\min_{R \in \Omega_{ij}} C_R = \arg\min_{R \in \Omega_{ij}} (\sum_{i \in R} u_i^b)^{1/b}.$$

Two versions of MSR correspond to the following extreme cases for this *utility* function:

CASE $b=1$: This routing (MSR-C) chooses the route with the maximum *combined* remaining battery life of each node on the route

(9) $$\arg\min_{R\in\Omega_{ij}} C_R = \arg\min_{R\in\Omega_{ij}} (\sum_{i\in R} u_i).$$

This case does not favor any one node, and considers the "battery life" of the entire route.

CASE $b=\infty$: This routing (MSR-W) assumes that the "weakest" node will collapse a route. Hence, the route with the strongest "weakest" node is selected.

(10) $$\arg\min_{R\in\Omega_{ij}} C_R = \arg\min_{R\in\Omega_{ij}} (\max_{i\in R} u_i) = \arg\min_{R\in\Omega_{ij}} (\frac{1}{\min_{i\in R} T_i}).$$

The implementation of this strategy assumes that the estimates T_i are known. Accuracy of these estimates is crucial for good performance of the MSR. We consider a quasi-stationary scenario when the volatility of the power-draining rates r_i is low, and consequently the future draining rates can be estimated at moment t from the historical data as follows:

(11) $$r_i \approx r_i(t) = \frac{P_i(0) - P_i(t)}{t},$$

where $P_i(t)$ is the remaining battery power at node i at moment t assuming that the network started functioning at the moment $t=0$.

NETWORK IMPLEMENTATION

We assume that initially nodes transmit using power $P^{\max}$, and route packets according to the *minimum number of hops* to the destination. After the first transmission by node i, the "life expectancy" of node i is estimated as follows:

(12) $$T_i = P_i(t)/r_i(t),$$

where the estimate of the battery power draining rate $r_i(t)$ is given by (11). Then, the link costs are computed according to (6)-(7), and propagated throughout the network. If a cost of a particular link has not been computed within a specified amount of time because no data packet was transmitted on that link, a "boost" packet is transmitted on the link and the link cost is computed. Once all of the link costs have been computed, the routing protocol is now MSR. We assume that estimates $\bar{S}_{ij}$ in (5) updated on a per packet basis as follows:

(13) $$\bar{S}_{ij} = (1-a)\frac{(E_b/I_0)_{ij}}{P_{ij} r_{ij}^{-h}} + a\bar{S}_{ij}$$

where $(E_b/I_o)_{ij}$ is the bit energy-to-interference ratio for current transmission and a is a smoothing factor. At the first time node j receives transmission from node i, an initial value for $\bar{S}_{ij}$ is computed as follows:

(14) $$\bar{S}_{ij} = \frac{(E_b/I_0)_{ij}}{P^{\max} r_{ij}^{-h}}$$

The MSR path costs must be periodically circulated around the network. This information can be passed around via data packets, acknowledgements, and special control packets known as packet radio organization packets (PROPs) [6]. For this initial implementation we assume an underlying information dissemination scheme. A dynamic routing table is maintained by each node. For each destination, a node stores the outgoing link for the most efficient route and the corresponding path cost, distance to the destination, and the necessary transmitter power. Since the network conditions are changing, routing tables are continually updated, and the transmission power is altered on a per packet basis according to (5). Before an update, if a link cost is deemed out-dated, i.e., the cost has not been recomputed within a specified interval before an update, a "boost" packet is transmitted on that link in order to compute a current link cost.

We use the modeling and simulation tool OPNET to build a network prototype and execute the simulation. We assume the MANET uses the ALOHA random access protocol. We consider a slow fading (log-normal shadowing) environment. We assume that a node has knowledge of the transmitter power used to communicate with it and hence, uses (13) to update the estimate of $\bar{S}_{ij}$. A list of the simulation parameters is given in Table 1.

Parameter	Value
Network area	900m * 500 m
Data Rate	830 Kbps
Max range	250m
Min frequency	2.4 GHz
Bandwidth	830 KHz
Modulation	Direct-Sequence BPSK
Processing Gain	20 db
Packet length	100 bits
Noise Figure	20 db
Background temperature	290 K
SNR_LIM	0.05

Table 1. Network simulation parameters

SIMULATION RESULTS

We compare the performance of MSR-C and MSR-W to that of SDR and MPR, and present our preliminary results. SDR is based on distributed Bellman-Ford shortest distance routing with the cost of a link equal to the distance between the transmitter and intended receiver [5]. MPR uses distributed Bellman-Ford routing with the transmission power required on a link as the link cost [1]. Figures 1 and 2 represent simulation results for scenarios without and with mobility, respectively. In the scenario with mobility we assume that nodes follow a *random walk* at a speed of 4 m/s. Figures 1a and 2a show the number of disconnected nodes in the network versus simulation time. Figures 1b and 2b show the remaining battery power at the “weakest” node in the network, i.e., node with the least remaining battery power versus simulation time. Finally, figures 1c and 2c show the overall network efficiency - number of successful transmissions divided by number of total transmissions.

Figures 1a and 2a clearly demonstrate that MSR substantially prolongs the connectivity of the network as compared to SDR and MPR. For scenario without mobility (figure 1a), the number of disconnected nodes is an increasing function of time, i.e., once a node becomes disconnected it will not rejoin the network. However, for scenario with mobility (figure 2a), nodes may move in and out of the transmission range and the number of disconnected nodes may increase or decrease with time. As can be seen from these figures, MSR-C preserves connectivity better than MSR-W. This observation can be qualitatively explained by examining the remaining power at the "weakest" node, i.e., the node with the least remaining power. Figures 2a and 2b illustrate that MSR achieves longer connectivity by adapting routes to preserve the battery power. Since SDR and MPR do not take into account the remaining battery life, they causes depletion of the battery power at early stages of the network operation. As can be seen from figure 1b, and especially from figure 2b, the draining rate of the battery power at the weakest node for MSR-W abruptly changes with time. This is because MSR-W is sensitive to accuracy of the estimation of the future draining rates for the battery power. Note that it is more difficult to accurately estimate the future draining rates for scenario with mobility due to changes in the network topology. Figures 1c and 2c show that MSR also prolongs the operating mode of high efficiency. For all protocols as the number of disconnected nodes in the network increases, the efficiency drops.

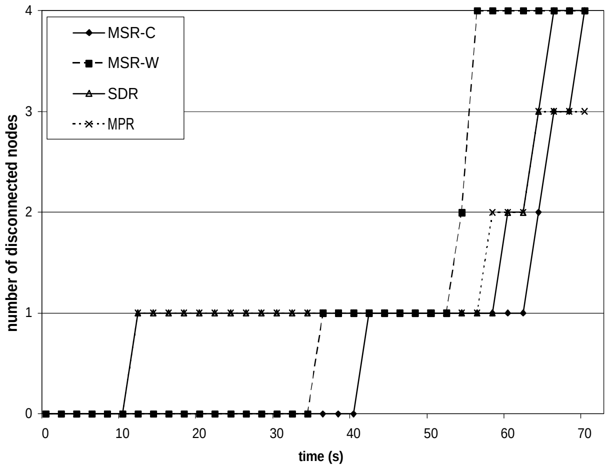

Fig.1.a: Number of disconnected nodes for scenario without mobility

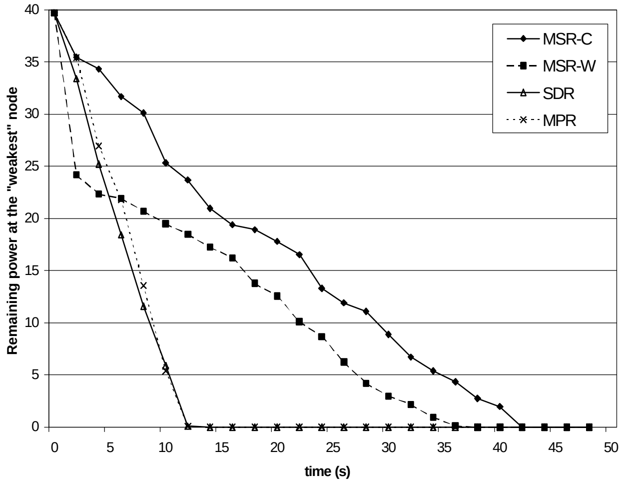

Fig.1.b: Remaining battery power in Watts at "weakest" node for scenario without mobility

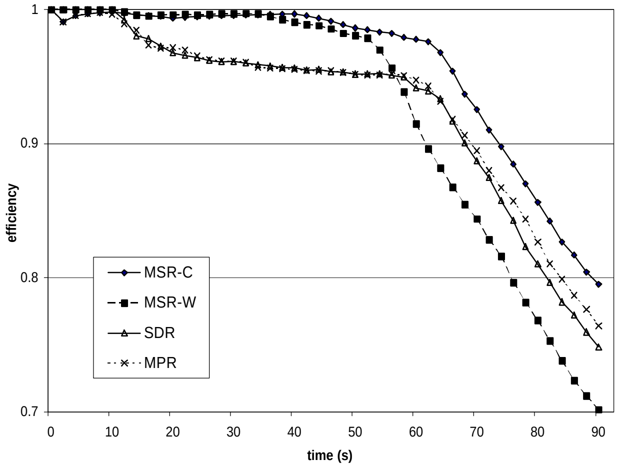

Fig.1.c: Efficiency for scenario without mobility

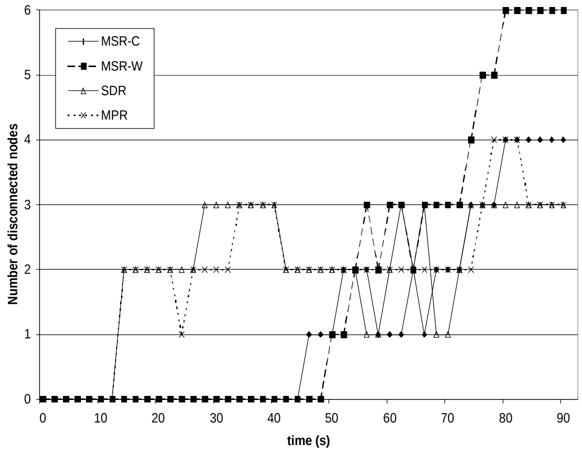

Fig.2.a: Number of disconnected nodes for scenario with mobility

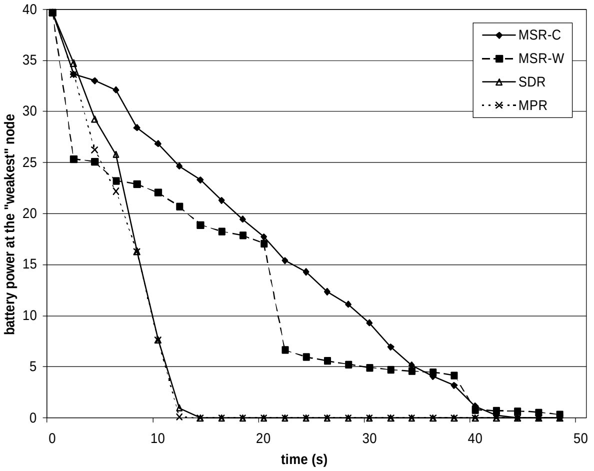

Fig.2.b: Remaining battery power in Watts at "weakest" node for scenario with mobility

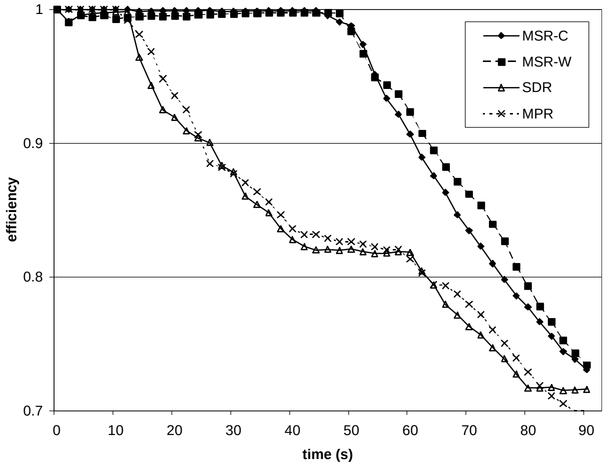

Fig.2.c: Efficiency for scenario with mobility

CONCLUSION

We developed a framework for Maximum Survivability Routing for wireless MANET, where the routing is aimed at preserving the network connectivity by choosing routing path according to the remaining battery life of nodes along the route. We showed that MSR exhibits superior performance in non-homogeneous MANET networks, i.e., when nodes have different battery power-draining rates (e.g. due to different bit transmission rates) or initial battery powers (e.g., humans and vehicles). We considered quasi-stationary scenarios when battery power draining rates are estimated from the historical data. Future research will concentrate on developing adaptation techniques for essentially non-stationary scenarios.

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