Utility-based Power Control Routing Mechanism for Energy-aware Optimization in Mobile Ad Hoc Networks

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ABSTRACT

In this paper, we propose a newly energy-efficient routing protocol, which is called *Maximum Utility Routing* (MUR), in mobile ad hoc networks (MANETs) so as to investigate the minimum energy and maximum lifetime issues together. We present a utility-based framework so as to meet various incompatible constraints simultaneously and fairly. To explore this issue, we use the concepts and mathematics of microeconomics and game theory. Through simulation results, we show that our routing scheme has much better performance especially in terms of network efficiency, network lifetime, and average power consumption.

I. INTRODUCTION

In power-sensitive ad hoc mobile wireless networks, transmitter power as a routing metric should be adjusted in order to achieve key objectives, including minimizing power consumption, maximizing the network lifetime, improving the network capacity, and maintaining the required link QoS by adapting node movements. However, these objectives cannot be satisfied concurrently by employing existing energy-aware routing protocols proposed so far in MANETs. In particular, if any routing scheme focuses on maximizing the network lifetime, it cannot minimizes the overall transmission power for each connection. To solve this problem, we propose a newly energy-efficient routing protocol, which is called *Maximum Utility Routing* (MUR), in MANETs so as to investigate the minimum energy and maximum lifetime issues together. In this paper, we present a utility-based framework so as to meet these incompatible constraints simultaneously and fairly. To explore this issue, we use the concepts and mathematics of microeconomics and game theory. A link's *utility function* defined in our study is a measure of the link's preference regarding the signal-to-interference-and-noise ratio (SINR) at the receiver, the transmitter power, and the transmitter's remaining battery capacity. Each transceiver should adjust its transmitter power such that its own utility will be maximized. Since each link in the network will try to maximize its own utility, regardless of what happens to the other links, this problem is a typical non-cooperative N-person game [2]. For simplicity, we study one special case by defining the utility as a linear function. Under this framework, our aim of MUR proposed is to find a route with the maximum total value of utilities over all links to the destination.

II. UTILITY-BASED POWER ADJUSTMENT

Consider a transmission scenario involving N links. The transmitter power of transmitter i to receiver j is P_{ij}. Let G_{ij} be the link gain from transmitter i to receiver j, and let η_j be the background noise received at receiver j. $\mathbf{P}_{-ij}$ denotes the vector of powers of all transmitters to receiver j except the power of transmitter i. Then we have

$$SINR_{ij} = \frac{G_{ij}P_{ij}}{\sum_{k \neq i} G_{kj}P_{kj} + \eta_j} = \Phi_{ij}(\mathbf{P}_{-ij}) \cdot P_{ij}. \qquad (1)$$

Notice that the *SINR* is a linear function of its transmitter power if all the other transmitters fix their own transmitting power. Generally, a measure of the link QoS is the *SINR* at the receiver. Let BC_i^R be the remaining battery capacity of transmitter i. For simplicity, we assume that BC_i^R is a function of P_{ij}, i.e., $f_i(P_{ij})$. The use of the remaining battery capacity prevents nodes from being overused or abused, thereby increasing their lifetimes and the time until the network is partitioned. As a result, the link's *utility function* $U_{ij}(SINR_{ij}, P_{ij}, BC_i^R)$ can be defined as a function of the achieved QoS $SINR_{ij}$, the transmitter power P_{ij} and the remaining battery capacity BC_i^R. We observe the following three situations from the utility function. First, if P_{ij} and BC_i^R are fixed, we have preference with better $SINR_{ij}$. Secondly, given $SINR_{ij}$ and BC_i^R, we seek to save P_{ij}. Last, if $SINR_{ij}$ and P_{ij} are fixed, we want to choose a transmitter with more remaining battery capacity. These observations give $\partial U_{ij} / \partial(SINR_{ij}) > 0$, $\partial U_{ij} / \partial P_{ij} < 0$ and $\partial U_{ij} / \partial(BC_{ij}^R) > 0$. It is typically natural that the utility function has concavity as presented in [1]. Our goal is to maximize the value of the utility function. Since each link in the network will try to maximize its own utility, regardless of what happens to the other links, this problem is a typical non-cooperative N-person game [2]. If a positive power P_{ij} is a local optimum for a utility-maximization problem, we have $\partial U_{ij} / \partial P_{ij} = 0$, i.e.,

$$\frac{\partial(U_{ij}(SINR_{ij}, P_{ij}, BC_i^R))}{\partial P_{ij}}$$

$$= \frac{\partial U_{ij}}{\partial(SINR_{ij})} \cdot \Phi_{ij}(\mathbf{P}_{-ij}) + \frac{\partial U_{ij}}{\partial P_{ij}} + \frac{\partial U_{ij}}{\partial(BC_i^R)} \cdot f_i'(P_{ij}) = 0. \quad (2)$$

If transmitter i satisfies the equation (2), then its transmitter power P_{ij}^* is the optimal transmitter power such that its own utility will be maximized. In this paper, transmitter power is adjusted using the iterative algorithm proposed in [1]. This simple algorithm can easily be proved to be efficiently convergent [1].

III. LINEAR UTILITY FUNCTION

For simplicity, we present a special case study by defining the utility as a linear function. The associated formulation is expressed as:

$$\max_{P_{ij}} \quad U_{ij}(SINR_{ij}, P_{ij}, BC_i^R)$$

$$= \alpha \cdot \frac{SINR_{ij}}{\Gamma_{ij}} - \beta \cdot \frac{P_{ij}}{P_{ij}^{\max}} + \gamma \cdot \frac{BC_i^R}{\Omega_i}$$

$$= \left(\frac{\alpha}{\Gamma_{ij}} \cdot \frac{G_{ij}}{\sum G_{kj}P_{kj}} - \frac{\beta}{P_{ij}^{\max}} + \frac{\gamma}{\Omega_i} \cdot \kappa \right) \cdot P_{ij} = \Psi_{ij}(\mathbf{P}_{-ij}) \cdot P_{ij} \quad (3)$$

$$s.t \qquad SINR_{ij} \geq \Gamma_{ij}, \; 0 \leq P_{ij} \leq P_{ij}^{\max}, \; BC_i^R \geq \Omega_i,$$

where Γ_{ij} is the desired *SINR* threshold for link $i \rightarrow j$ and Ω_i is a protection margin of battery capacity for transmitter i. We assume that BC_i^R is a linear function of P_{ij}, i.e., $\kappa \cdot P_{ij}$. In this special case, the utility function can be represented as a linear function of its transmitter power if all the other transmitters fix their own transmitting power. Parameters α, β and γ are designing factors indicating the preference regarding the corresponding variable respectively. According to the setting of these factors, the network performance could be different. In this paper, the values of parameters α, β and γ are respectively set to 1.5, 1 and 0.4 throughout extensive simulations.

IV. Maximum Utility Routing

We define *route utility* as the total value of link metrics to the destination. Here, a link metric is a value of the utility function for each link. By MUR protocol, a source node selects a route with the maximum route utility among feasible ones. In MUR, an on-demand routing strategy is used as a route selection method. During the routing process, there is notably one thing as follows: if there is no route satisfying the constraint $BC_l^R \geq \Omega_l$ in Problem (3), our protocol selects a route l with the maximum value of BC_l where BC_l is the minimum value of remaining battery capacities of nodes in route l.

V. Numerical Results

We compare three routing protocols: 1) Maximum Utility Routing (MUR), 2) Minimum Power Routing (MPR) [3], 3) Shortest Distance Routing (SDR) [4]. The link gain G_{ij} is modeled as a product of two variables, $G_{ij} = A_{ij} \times D_{ij}$, where A_{ij} is for the variation in the received signal due to shadow fading, and assumed to be independent and log-normally distributed with a mean of 0 dB and a standard deviation 8 dB, and D_{ij} represents the large scale propagation loss, which depends on the distance between the transmitter and the receiver. We consider the 4th power-decay rule. It is assumed that all of the mobile nodes in the network are homogeneous and the network uses the ALOHA random access protocol. Other parameters are shown in Table 1.

Parameter	Value
Network coverage area	$1000\,m \times 600\,m$
Number of nodes in the network	25 (20% stationary, 80% mobile)
Maximum transmitter power $(P^{\max})$	$500\,mW$
Minimum Frequency	$2.4\,GHz$
Initial Battery Capacity	$40\,W$
Data rate	$1\,Mbps$
Node mobility	$5\,m/s$
Packet generation rate	10 packets/second/node
SINR threshold (Γ)	$10\,dB$
Protection margin of battery capacity (Ω)	$10\,W$

Table 1. Simulation parameters

Fig. 1 shows the overall network efficiency of three routing schemes. *Network efficiency* is defined as the number of successful transmissions divided by the number of total transmissions. Our MUR scheme shows better performance than MPR and SDR schemes in terms of efficiency, since MUR uses the utility function considering relative preference of good QoS. In Fig. 2, the remaining battery capacity at the "weakest" node in the network of three routing schemes is shown. Our MUR outperforms MPR and SDR, because MUR considers the remaining battery capacity in the utility function. Especially, MPR and SDR schemes give similar results, since they do not take into account the remaining battery capacity. In addition, we consider the *network lifetime* to be the period from the time instant when the network starts functioning to the time instant when the first node runs out of battery capacity. Network lifetimes of MUR, MPR and SDR are respectively 46.8s, 18.5s and 17.3s. Fig. 3 shows the effect of variable mobility on the average power consumption. MPR has the highest performance. This is because MPR finds the path that will require the least amount of total power expended to route data packets. We can see that our MUR delivers slightly lower performance than MPR. One notable point is that mobility gives little influence.

VI. CONCLUSION

We have proposed a newly energy-efficient routing (MUR) protocol which utilizes an economic-based framework to find local optimum transmitter power of maximizing each link's utility.

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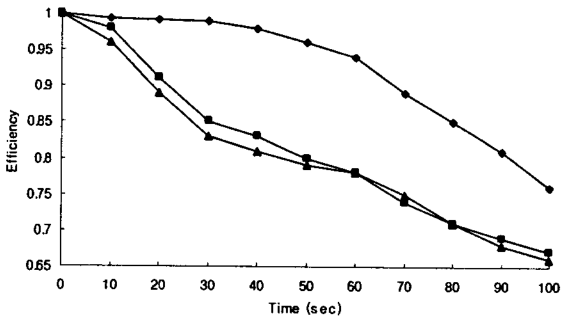

Fig 1. Network efficiency

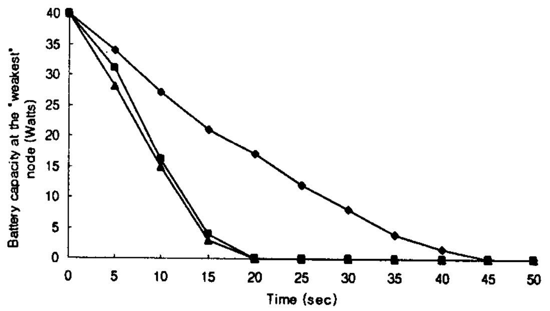

Fig 2. Remaining battery capacity at the "weakest" node in the network

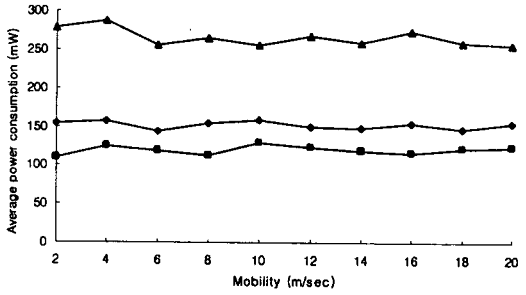

Fig 3. Average power consumption under different mobility

◆ MUR

■ MPR

▲ SDR