An Architecture to Support Power Saving Transmission Services with Route Stability in Mobile Ad-hoc Wireless Networks

Beongku An* and Nam-Soo Kim**

Abstract **— In mobile ad-hoc wireless networks, one of the most important challenging issues is how to conserve energy, maximizing the lifetime of route (networks) in the view points of both power and mobility of nodes. However, many transmission methods presented in the previous works can not satisfy these two objectives simultaneously. To obtain these two goals, in this paper we propose an architecture to support power saving transmission services with route stability in mobile ad-hoc wireless networks. The proposed architecture consists of two parts, the underlying route stability method to support route (network) lifetime and the power saving transmission methods. The performance evaluation of the proposed architecture is achieved via simulation and analysis.**

Index Terms **— Cross-layer, Diversity, Mobile ad-hoc wireless networks, Power saving transmission, Route (network) lifetime**

I. INTRODUCTION

Mobile ad-hoc networks [1] are an ideal technology to establish an instant communication infrastructure for military and civilian applications in which nodes aremobile. Such networks have dynamic, sometimes rapidly changing, random, multihop topologies. Management functions, routing [2][3] and scalability in mobile ad-hoc wireless networks present more complex problems than in wired or last-hop networks, due to the random movement of nodes, the bandwidth and power limitations, and the lack of fixed infrastructure. So, there are several issues in mobile ad-hoc wireless networks. In this work, we focus on just both route stability and power saving issues among recent issues [4] in mobile ad-hoc wireless networks. In this paper, the proposed architecture consists of as follows. First, an underlying route stability method to support route (network) lifetime efficiently. Second, power saving transmission methods such as a direction guided transmission technique to support power saving services using location-based information via Global Position System(GPS), a directional transmit antenna and antenna receive diversity techniques with maximal ratio combining(MRC) to increase the received SNR (i.e., to save transmission power) in Rayleigh fading. Third, the combination system technique to efficiently support both power saving communication and route(network) lifetime. The remaining parts of this paper are organized as follows. We present the related works in section 2. The proposed architecture is presented in section 3. In section 4, we describe the performance evaluation of the proposed architecture. We then conclude this paper in section 5.

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II. RELATED WORKS

The purpose of this paper [5] is to present distributed mobility-aware scheme for route selection where each node evaluates its path. This work develops and uses two similar metrics, node mobility metric and path stability metric, to enhance the performance of existing routing protocols under wide range of mobility. By making use of user's non-random mobility pattern, this scheme can predict the future state of a network topology and thus provides the stable route. This paper [6] introduces a new metric that can be used for route selection before the actual forwarding of the packet along that route takes place. In order to define the metric, this paper makes use of a dissemination mechanism that distributes GPS location information and other nodes attributes such as transmission radius and velocity. Based on the location information available locally, when a source node has to transmit a packet to a given destination, it will compute one or more routes to that destination and then it will associate with each route a value that bounds the probability that the route exists for the duration that it is traversed by the packet. Based on this probability, any source node can then select the route that best serves the purposes of a specific application. The local computation of the route availability is based on a simple closed form expression. This paper [7] proposes architecture and protocols for supporting geomulticast services in a cost (e.g. power, control overhead, and delay) effective way and with high message delivery accuracy in mobile ad-hoc wireless networks. This work proposes a direction guided routing (DGR) protocol in order to save transmission power and reduce control overhead to final destinations. This work [8] presents a power-aware routing protocol in mobile ad-hoc wireless networks. The goal of this article is to maximize the life-time of each mobile node and use the battery fairly. To obtain this goal, this work uses battery capacity instead of cost functions as a route selection metric, and introduces a conditional max-min battery capacity routing scheme. In this paper [9], a power-aware routing algorithm for energy-efficient routing that increases the operational life-time of multi-hop wireless networks. This method identifies the capacity of a node not just by its residual battery energy, but also by the expected energy spent in reliably forwarding a packet over a specific link. Using a max-min formulation, the algorithm selects the path that has the largest packet capacity at the critical node. In this algorithm, the cost of choosing a particular link at any instant is defined as the idealized maximum number of packet that can be transmitted by the transmitting node over the specific link, assuming the complete absence of any other cross traffic at that node.

This paper [10] describes the concept of transmit diversity and explains the features of selected transmit diversity techniques. This paper [11] presents a cross-layer ad-hoc routing approach based on link connectivity assessment in the network topology. The routing topology suggested in this work leverages cross-layer interactions among the networking, data-link, and physical layers, for enhanced adaptability to varying network topology and link states. This paper [12] tries to increase the life-time of the individual nodes, and hence the network's life-time, by routing and assignment channels to multiple-hop calls so that the resulting transmission power is minimized. By enforcing a reuse distance similar to the frequency reuse factor in AMPS cellular service, this paper can route and assign channels to arriving calls in a peer-to-peer network so as to significantly reduce power requirements and interference. In this work [13], the proposed location-aided power-aware routing (LAPAR) protocol uses relay region. The relay region $R(s,r)$ of source node s and relay node r is defined as the set of destination node location where relaying through node r is more power-efficient than directly sending from node s. Therefore, if a node is within the relay region of $R(s,r)$, less communication power is consumed by relaying from s through r to the destination node than by sending directly from s to the destination node.

III. The Proposed Architecture

The proposed system architecture which is shown in figure 1 consists of two parts as follows: The first part (see in section 3.1) is the underlying route stability structure for supporting route (network) lifetime efficiently [14]. The second part (see in section 3.2) is the power saving transmission structure [8]. The direction guided transmission technique [7] is supported by the underlying route stability structure for power saving communication using location-based information. The message transmission via stable routes from a source node to a destination node is limited within the guided area, and hence the transmission power can be saved. The directional transmit antenna [15] and antenna receive diversity technique [15][16] with MRC increase the received SNR in Rayleigh fading. The increased SNR can reduce the transmission power. To increase the received SNR at transmit side, we adopt the directional antenna that focuses the transmit power only to the desired direction. Furthermore, we adopt the antenna receive diversity with MRC technique in fading channel to increase the received SNR at receive side. Finally, we present the combination technique [17] which is the combination approach of the direction guided transmission supported by underlying route stability structure, directional transmit antenna, antenna receive diversity to efficiently support both power saving communication and route (networks) lifetime.

3.1 The Underlying Route Stability Structure

In this section, we present an underlying route stability structure which can support route lifetime efficiently. The structure works as the underlying routing route (mesh) structure of the proposed architecture to efficiently support both power saving transmission and increased route (networks) lifetime(see in section 3.2). Fig. 2 shows the basic concepts of the modeling framework for supporting route stability [14]. We consider a mobile ad-hoc wireless network and let us denote by M_m the number of neighboring nodes of a mobile node m, and by s_m the corresponding set.

We also associate with each node m a set of variable features denoted by $a_{m,n}$ where node n is a neighbor of node m. In this paper, two nodes are considered neighbors if they can reach each other in one hop (e.g. direct communication). These variable features $a_{m,n}$ represent a measure of the relative speed among two nodes. Any change of the system can be described as a change of variable values $a_{m,n}$ in the course of time t such as $a_{m,n}(t) \to a_{m,n}(t+\Delta_t)$. Let us also denote by $v(m,t)$, the velocity vector of node m and by $v(n,t)$, the velocity vector of node n at time t. Please note that velocity vectors $v(m,t)$ and $v(n,t)$ have two parameters, namely speed and direction. The relative velocity $v(m,n,t)$ between nodes m and n at time t is defined as:

$$v(m,n,t) = v(m,t) - v(n,t) \qquad (1)$$

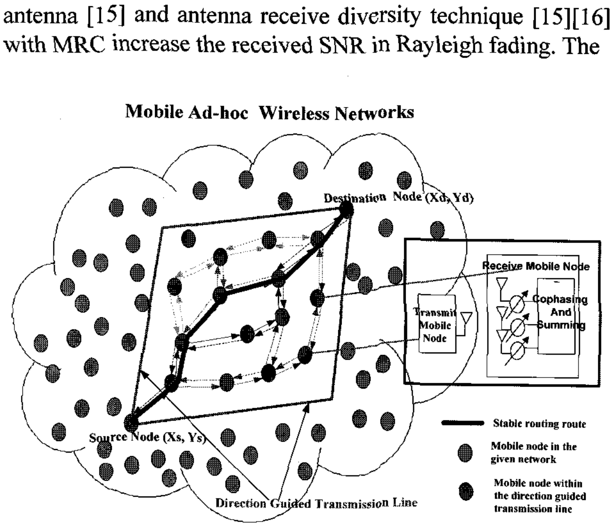

Fig. 1. The proposed architecture to support both power saving transmission and route(networks) life-time.

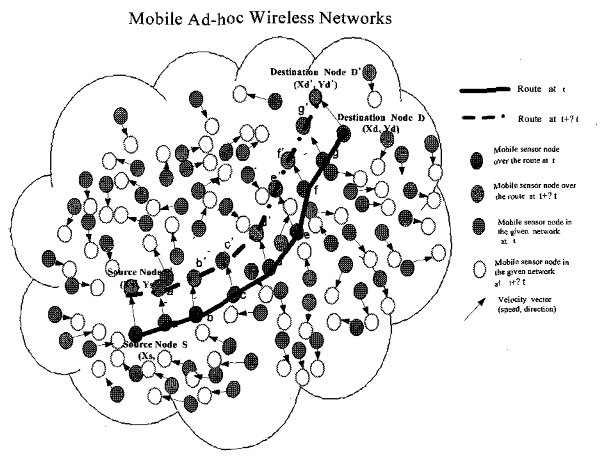

Fig. 2. The basic concepts of the underlying route stability structure to support both route stability and power saving transmission.

Then, the relative mobility between any pair (m,n) (of nodes during some time interval Δ_t is defined as their absolute relative velocity averaged over time. That is, any pair of nodes within a distance of z meters are considered to be neighbors. As mentioned earlier, the variable features considered here is the relative mobility between two nodes. Therefore, we have:

$$a_{m,n} = \frac{1}{N}\sum_{i=1}^{N} | v(m,n,t_i) | \quad (2)$$

where N is the number of discrete times that velocity information can be calculated and disseminated to other neighboring nodes within time interval Δ_t.

Based on this, we can define the entropy $H_m(t,\Delta_t)$ at mobile m during time interval Δ_t. The entropy [18] can be defined either within the whole neighboring range of node m (e.g. within set S_m), or for any subset of neighboring nodes of interest. In general, the entropy $H_m(t,\Delta_t)$ at mobile m is calculated as follows:

$$H_m(t+\Delta_t) = \frac{-\sum_{k\in F_m} P_k(t,\Delta_t)\log P_k(t,\Delta_t)}{\log C(F_m)} \quad (3)$$

Where

$$P_k(t,\Delta_t) = \frac{a_{m,k}}{\sum_{i\in F_m} a_{m,i}}$$

In this relation, by F_m we denote the set (or any subset) of the neighboring nodes of node m, and by $C(F_m)$ the cardinality (degree) of set F_m. If we want to calculate the local network stability (with reference to node m), then F_m refers to the set that includes all the neighboring nodes of mobile node m (e.g. $F_m = S_m$), while if we are interested in the stability of a part of a specific route then F_m represents the two neighboring nodes of mobile node m over that route. As can be observed from the previous relation, the entropy $H_m(t,\Delta_t)$ is normalized so that $0 \le H_m(t,\Delta_t) \le 1$. It should be noted that the entropy, as defined here, is small when the change of the variable values in the given region is severe and large when the change of the values is small [18]. In the following, we describe how to apply this model in order to measure the route stability. The local route (or the part of the route that represents the links of the path associated with an intermediate node), is stable

if $H_m(t,\Delta_t)$ is large while the local route is unstable if $H_m(t,\Delta_t)$ is small. However, in general in mobile ad-hoc wireless network the route between a source and a destination may traverse multiple intermediate nodes (hops). Let us present the route stability (RS) between two nodes S (source node) and D (destination node) during some time interval Δ_t as $\gamma = RS_{s,d}(t,\Delta_t)$. We also define and evaluate two different measures to estimate and quantify end to end route stability, denoted by $\gamma^1 = RS^1_{s,d}(t,\Delta_t)$ and $\gamma^2 = RS^2_{s,d}(t,\Delta_t)$, which is defined as follows, respectively:

$$\gamma^1 = RS^1_{s,d}(t,\Delta_t) = \prod_{i=1}^{N} H_i(t,\Delta_t) \quad (4)$$

and

$$\gamma^2 = RS^2_{s,d}(t,\Delta_t) = \min_{i=\{1,2,3,\ldots,N\}} H_i(t,\Delta_t) \quad (5)$$

where N denotes the number of intermediate mobile nodes over a route between the two end nodes (S,D).

3.2 Power saving transmission method: The analysis

Mobile ad-hoc wireless networks are power limited system, where each node of the mobile ad-hoc networks has limited power. In this section, we present power saving transmission methods with theoretical analysis for mobile ad-hoc wireless networks.

3.2.1 Direction-guided transmission

In this work, we present a direction-guided transmission (DGT) method [7] over the underlying route stability structure to support both power saving transmission and increased route (network) lifetime in mobile ad-hoc wireless networks. We assume each mobile node can get location information via Global Positioning System (GPS). Figure 3 shows the basic concept of direction-guided transmission method to support power saving transmission.

The proposed DGT method consists of four steps.

Step1: Decision of destination position (or area)

Step2: Decision of direction-guided line

Step3: Construction of the underlying routes (mesh) stability structure within the Direction-guided transmission line. This underlying route stability structure is presented in *section 3.1*

Step4: Transmission of packets from a source node to a destination node via the mesh routes(i.e., underlying route stability structure) supporting stability within the direction-guided line.

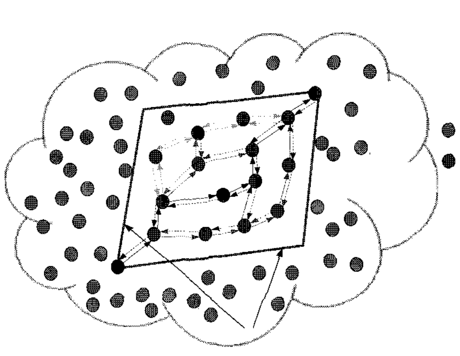

Fig. 3. The basic concept of direction-guided transmission method to support power saving transmission.

We assume the total number of the mobile nodes are K between a source node and a destination node in a given mobile ad-hoc network, while the number of mobile nodes within the areas of direction guided transmission (DGT) are N, where $N \leq K$. In other words, the number of mobile nodes which are participated in the transmission are N in DGT, while K in conventional system. We want to send a data from a source node to a destination node. Where we assume the transmit power of each node equals to P[W]. In this environment, the power consumption is equal to $(K-1)P$ [Watts] in conventional networks (i.e, not use of DGT) while the power consumption is just $(N-1)P$[Watts] in the mobile ad-hoc wireless networks using DGT. Hence, the transmission power gain $\Gamma_{DGT}(dB)$ of the network with DGT to conventional transmission system can be written by

$$\Gamma_{DGT}(dB) = 10\log_{10}\{(K-1)/(N-1)\} \tag{6}$$

Furthermore, the packets are just transmitted via stable mesh routes within the DGT lines with route priority which depends on the route stability (i.e., $\gamma^1(\gamma^2)$, see equations (4) and (5)). Therefore, the transmission rate is increased, while retransmission rate for reliable packet transmission services is decreased. Finally, we can get power saving for packet transmission.

3.2.2 Power saving method using directional transmit antenna

In the conventional mobile ad-hoc networks, an omnidirectional transmit antenna which transmits the packet information to all directions is used. Thus, some packets can be transmitted to unwanted directions. Consequently, it consumes the unwanted power. If the destination information is known, we can apply the directional transmit antenna towards the destination node for the transmit power saving. The power saving transmission using directional antenna is determined by the half power beam width (HPBP) of the antenna. Horn antenna in microwave band and phase array antenna in low frequency band are representative directional antennas. The packet from a mobile node is transmitted to all directions in the conventional mobile ad-hoc wireless networks, while in this research the packet from a mobile node is transmitted to just the target area(or point) using both a directional transmit antenna and DGT. The power gain $G_D(dB)$ with a directional transmit antenna can be written by [15]

$$G_D(dB) = 10\log(\frac{2\pi}{DA}) \tag{7}$$

where DA is the HPBW of the directional antenna in radian.

Since the number of mobile nodes within the area of DGT are N, the transmission power gain $G_T(dB)$ using a directional transmit antenna within the area of DGT between a source node and a destination node can be obtained by

$$G_T(dB) = (N-1)G_D(dB) \tag{8}$$

3.2.3 Power saving method using antenna receive diversity

When the height of the receiving antenna is low and the moving objects are located around the receiving antenna, the receiving signal strength in mobile ad-hoc wireless networks is severely fluctuated. This phenomena is called fading which degrades system performance. Antenna diversity technique mitigates the fading fluctuation without spectrum expansion by using several receiving antenna, hence improves system performance and lessen the power consumption. Therefore, we apply this receiving diversity technique [10] to the mobile ad-hoc wireless networks. We assume the Rayleigh fading which only has the reflected waves. The receiving signals at multiple antennas are reached from various paths. Because these signals are independently faded, the probability that this signal is affected by a deep fade, which occur simultaneously on all of the antenna branches, is very low. Accordingly, by combining of the received signals it is possible to obtain a resultant signal where the effects of fading are minimized. That is the receiving diversity obtains the receiving gain, and the signal-to-noise ratio (SNR) is increased. Consequently, the transmit power is decreased.

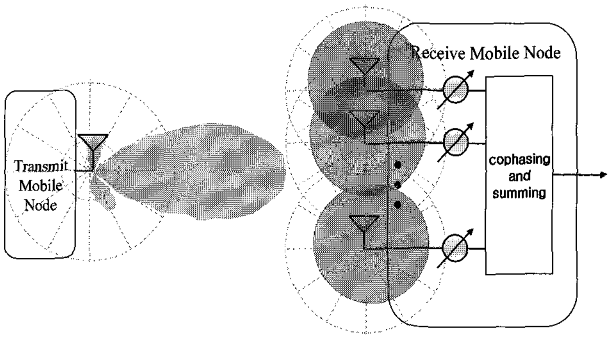

Fig. 4. The basic concept of antenna receive diversity to support power saving transmission.

There are several receiving diversity techniques, among them MRC is well known as the most efficient method in Rayleigh fading conditions. In the structure of MRC, the received signal of each antenna branch is weighted proportional to the received signal amplitude and then combined after cophasing. When the number of the received antennas is L and each received signals are independent, the received SNR of MRC output increases L times. The output SNR of a MRC receiver with L receiving branches can be given by [15][16]

$$\gamma = \sum_{l=1}^{L} \gamma_l \tag{9}$$

where $\gamma_l (1 \leq l \leq L)$ is the SNR of each branch, and the L denotes number of branches. In equation (9), the output SNR means the sum of the SNR of each branch. The bit error probability (BER) of Binary Phase Shift Keying (BPSK) in additive white Gaussian noise can be written by

$$p_b = Q(2\gamma) \tag{10}$$

where

$$Q(x) = \frac{1}{\sqrt{2\pi}} \int_x^{\infty} \exp(-\frac{u}{2}) du \tag{11}$$

Assuming each of the receiving signals is independent and Rayleigh faded, the average BER of BPSK is given by [8]

$$P_e = \left(\frac{1-\mu}{2}\right)^L \sum_{l=0}^{L-1} \binom{L-1+l}{l} \left(\frac{1+\mu}{2}\right)^l \quad (12)$$

Where

$$\mu = \sqrt{\frac{\Gamma}{1+\Gamma}} \quad (13)$$

where Γ is assumed to be identical for all channels, denotes the average SNR of each branch. The power gain $\Gamma_G(dB)$ of a dicersity system to non-diversity system can be written by

$$\Gamma_G(dB) = \Gamma_1(dB) - \Gamma_L(dB) \quad (14)$$

where $\Gamma_1(dB)$ and $\Gamma_L(dB)$ denote the average receiving SNR that satisfies the pre-determined BER of a non-diversity system and of a diversity system, respectively. Since the number of mobile nodes within the area of DGT are N, the power gain $\Gamma_T(dB)$ of a receiving diversity system between the source node and the destination node are given by

$$\Gamma_T(dB) = (N-1)\Gamma_G(dB) \quad (15)$$

3.2.4 The combination architecture to support both power saving transmission and route (network) life-time

Fig. 1 shows the basic concept of the combination architecture to support both power saving transmission and route (network) lifetime. The total power gain $G_{sys}(dB)$ of the combined power saving transmission method [17] which uses the combination strategy of DGT supported by underlying route stability structure, directional transmit antenna, and receiving diversity antenna to transmit a packet between a source node and a destination node in mobile ad-hoc wireless networks is given from equations (6), (8) and (15) by

$$G_{sys}(dB) = \Gamma_{DGT}(dB) + G_T(dB) + \Gamma_T(dB) \quad (16)$$

IV. PERFORMANCE EVALUATION AND ANALYSIS

First, we evaluate the performance of the underlying route stability structure to support route (network) lifetime efficiently. We use OPNET (Optimized Network Engineering Tool) for performance evaluation. In order to evaluate the proposed modeling framework and corresponding parameters, a mobile ad-hoc wireless network consisting of 50 nodes that are placed randomly within a rectangular region of 1km x 1km is modeled. Each node is assumed to have constant radio range of Z =200 meters. That is, any pair of nodes within a distance of Z meters are considered to be neighbors. Throughout our evaluation, we assume that a link fails, or reappears, as a node goes out or in transmission range of another node, due to the mobility of the nodes. Mobile nodes are assumed to be moving around throughout the network. Mobile nodes are assumed to be moving around throughout the network. The speed and the direction of each move are uniformly distributed, with speed range [0, v_{max}] km/hr and direction range [0, 2π], respectively. Fig. 5 and fig. 6 show the packet delivery ratio (PDR) and the route lifetime as a function of mobility speed respectively. As we can see in fig. 5 and fig. 6, the PDR and route lifetime are slightly decreased according to the increasing of the node mobility speed. The reason is that ERPM uses the node mobility information for route setup, then in this network environments the route setup is much more unstable. Therefore, the PDR and route lifetime are decreased together according to the increasing of the node mobility speed. As it is observed from figure 5 and fig. 6, the lifetime of the route between a pair of end nodes is large when the route stability estimated by our proposed model (as calculated by relations equation (4) and (5)) is high. Also, as can be seen from figure 5 and figure 6, the routes with higher estimated route stability values (as calculated by relations equation (4) and (5)) have also higher measured packet delivery ratio(i.e., route availability).

Second, we present a performance evaluation for the power saving transmission structures using direction-guided transmission, directional transmit antenna, antenna receive diversity, and combination approach respectively. We assume that the total number of the mobile nodes in the mobile ad-hoc wireless networks are K, and the number of the mobile nodes within the DGT areas are N. Each node has a directional transmit antenna with HPBW of $2\pi/3$ radians and receiving diversity antennas. Also, we assume the transmit power of each node equals to P [W]. Table 1 shows the transmission power saving gain for the presented four power saving transmission structures. If we apply the DGT to the mobile ad-hoc wireless networks, the power gain is $\Gamma_{DGT}(dB) = 10\log_{10}\{(K-1)/(N-1)\}$ between a source node and a destination node. If we use the directional transmit antenna, the power gain which is obtained from a pair of mobile nodes is 4.77 dB. The total power gain of N mobile nodes within the DGT area is $4.77(N-1)$ dB. If we use receive diversity antenna, the power gain which is obtained from a pair of mobile nodes is 17.7 dB. Thus, the total power gain of N mobile nodes within the DGT is 17.7 $(N-1)$ dB. The total power gain $G_{sys}(dB)$ of the combined power saving transmission method which uses the combination strategy of DGT, directional

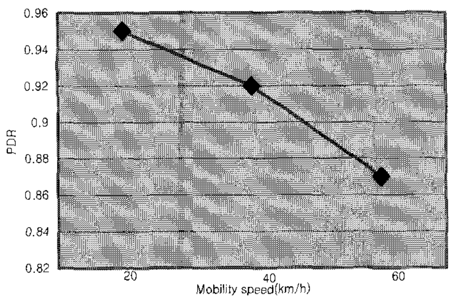

Fig. 5. Packet delivery ratio.

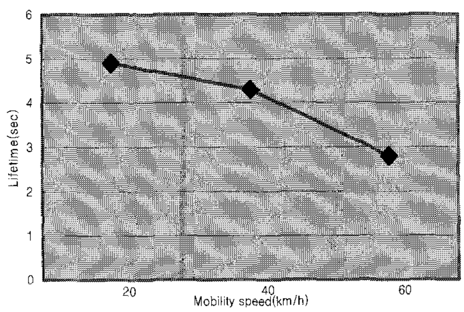

Fig. 6. Route lifetime.

Table 1. The power gain for the power saving transmission structures

Power Saving Transmission Methods \ Power Saving	Power Saving Gain (dB)
General Method	0
DGT Method over the Route Stability	$10\log_{10}\{\frac{(k-1)}{(N-1)}\}$
Directional Transmission Antenna Method within DGT	$4.77\times(N-1)$
Antenna Receive Diversity Method within DGT	$17.7\times(N-1)$
Combination Approach Method	$10\log_{10}\{\frac{(k-1)}{(N-1)}\}+(17.7+4.77)*(N-1)$

K is the total number of the mobile nodes in a given mobile ad-hoc network.
N is the number of mobile nodes within the areas of direction guided transmision (DGT), where $N \le K$

transmit antenna, and receiving diversity antenna between a source node and a destination node in mobile ad-hoc wireless networks is given as the sum of each power gain by

$$10\log_{10}\{(K-1)/(N-1)\}+(17.7+4.77)*(N-1)(dB) \quad (17)$$

The proposed combined power saving transmission architecture which combines DGT, directional transmit antenna, and receiving diversity antenna (i.e., the combination of the network layer technology and the physical layer technology) can reduce the power consumption for data transmission as well as extend the route (network) life-time, consequently support stable QoS in mobile ad-hoc wireless networks.

V. CONCLUSION

One of the most important challenging issues in mobile ad-hoc wireless networks is how to conserve energy for maximizing the lifetime of route (networks). However, many transmission methods presented in the previous works to solve these issues can not satisfy these two objectives, power saving and route stability, simultaneously. In this paper we propose an architecture to support power saving transmission services with route stability in mobile ad-hoc wireless networks. The main contribution and feature of the proposed architecture is how to support power saving transmission, maximizing the lifetime of route (networks) in the view points of both power and mobility of nodes simultaneously. The proposed architecture consists of two parts, the underlying route stability method to support route (network) lifetime and the power saving transmission methods. As we can be seen from performance evaluation and analysis, the proposed transmission architecture can efficiently support both route stability and power saving services in mobile ad-hoc wireless networks, consequently can decrease the transmit power consumption and extend route(network) lifetime in mobile ad-hoc wireless networks.

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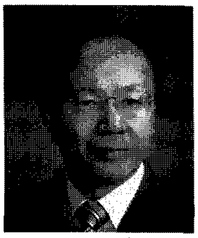

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