Probabilistic Real-time Routing Protocol for Mobile Ad-hoc Networks Based on IEEE 802.11b

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Abstract: - A mobile ad-hoc network (MANET) tries to solve the problem if the infrastructure is not available or inconvenient for its use such as in rural environments, trucks, cars or in battlefield. Mobile ad-hoc network consists of autonomous mobiles devices (nodes) that can also serve as router and can dynamically move around arbitrarily at appropriate speed in any direction resulting in an ever-changing topology of nodes. Real-time applications in MANET demand real-time forwarding which means messages in the network are delivered according to their end-to-end deadlines (packet lifetime). This paper proposes a novel real-time routing protocol that ensures high packet throughput with minimized packet overhead and prolongs the lifetime of MANET. Moreover, the proposed mechanism utilizes an optimal forwarding (OF) decision that takes into account of the link quality, packet delay and the remaining power of next hop nodes. The performance of proposed routing protocol has been successfully studied and verified through the simulation work based on IEEE 802.11b. The simulation results show that the proposed routing protocol possesses short average delay. Hence, it can be used for real-time routing.

Key-words: - An optimal node; Packet Reception Rate; MANET; Delivery Ratio.

1 Introduction

Mobility has contributed to the Internet boom which has more and more wireless devices connected to the Internet. Mobile networks can be classified into two types of networks: network with infrastructure called Mobile IP network and network without infrastructure called ad hoc network. The Mobile IP network tries to solve the problem of how mobile node may roam from its network to foreign network and still maintain connectivity to the Internet. MANET allows communication among nodes even if the communication infrastructure is not available or inconvenient for use such as in rural areas. MANET consists of autonomous mobiles devices (nodes) that can also serve as router and can dynamically move around arbitrarily at appropriate speed in any direction resulting in an ever-changing topology of nodes. Due to the mobility of nodes the topology of the networks changes unpredictably and thus, the most challenging issue is to design a routing protocol that trades off between information reachability and routes update overhead cost because network topology changes with time [1].

Since nodes in a network can serve as routers and hosts, they can forward packets on behalf of the other nodes and run user applications. As shown in Figure 1, ad hoc mode is designed such that only the clients within transmission range of each other can communicate. If a node in MANET wants to communicate with nodes located beyond this range, members of the network must operate as routers and perform routing services. The mobile nodes often have a limited transmission range. Hence, multi-hop paths are typically required to connect source/destination pairs.

Ad hoc networks can either be static or mobile. In static ad-hoc networks the position of a node may not change once it has become part of the network. In MANETs, nodes may move arbitrarily. Examples where MANETs may be employed are the establishment of connectivity among handheld devices or between vehicles. Since MANETs change their topology frequently and without prior notice, routing in such networks is a challenging task [2].
method is adopted to make nodes aware of history. The intelligent flooding protocol saves routing overhead because nodes selectively flood RREQ packets along predicted strong links and over predicted good frequencies. The intelligent flooding protocol can be divided into two parts, the space flooding protocol and the spectrum flooding protocol. However, SCRP required extra delay which is not practical for hard real-time applications.

Ying Dong and etc proposed an anonymous routing protocol with multiple routes called ARMR, which can satisfy all the required properties [7]. In addition, the protocol has the flexibility of creating fake routes to confuse the adversaries, thus increasing the level of anonymity. In terms of communication efficiency, extensive simulation was carried out. Compared with AODV and MASK, ARMR protocol gives a higher route request success rate under all situations and the delay of ARMR protocol is comparable to the best of these two protocols. However, ARMR was not designed for real-time applications because it required extra delay and packet overhead.

Seada and Helmy [8] proposed two protocols for geocast: geographic-forwarding-geocast (GFG) and geographic-forwarding-perimeter-geocast (GFPG). In the GFG, GPSR is used by nodes outside the region to guarantee the forwarding of the packet to the region. Nodes inside the region broadcast the packet to flood the region. GFPG uses both geocast and perimeter routing to guarantee the delivery of the geocast packet to all nodes in the region. The algorithm solves the region gap problem in sparse networks, but it causes unnecessary overhead in dense networks. The proposed geodirection-cast is a geographic routing instead of an ad hoc routing protocol. Geographic routing has several advantages: nodes require information only from their direct neighbours so discovery floods and state propagation are not required, and accordingly it has lower overhead and faster response to dynamics. Geographic routing is more scalable than ad hoc routing protocols and more suitable for WSN. Therefore, the proposed mechanism has an advantage than the forwarding mechanisms that are mentioned earlier. Most of the forwarding mechanisms use single forwarding path to send the data packets toward the destination area in geographic region. However, the delivered packets are not guaranteed to arrive at their destination region. In contrast, the geodirection-cast uses quadrant multi-hop forwarding toward the destination, which provides more guaranteed delivery ratio.

Reactive routing protocols such as Ad Hoc on Demand Distance Vector Routing (AODV) maintain only the routes that are currently in use, thereby reducing the burden on the network when only a small subset of all available routes is in use at any time [9]. Since routes are only maintained while in use, it is typically required to perform route discovery. Route discovery in AODV can lead to significant delays in ad hoc network with a large network diameter (measured in multiples of radio radius). In addition, a node in AODV protocol uses flooding to discover new paths, however, flooding causes congestion and experience long end-to-end delay.
AOMDV [10] extends the prominent AODV to discover multiple link-disjoint paths between the source and the destination in every route discovery. It uses the routing information already available in the AODV protocol as much as possible. It makes use of AODV control packets with a few extra fields in the packet header such as advertised hop count and route list which contains multiple paths. The main problem, which is called “route cutoff” in AOMDV, is that when there are one or more common intermediate nodes in a pair of link-disjoint paths, it cannot find both of the reverse paths. To reduce route discovery latency, it is necessary to find out all of the existing link-disjoint reverse paths.

S. Jain and etc Proposed Real time On demand Distance Vector (RODV) routing protocol [11]. RODV is a modification of the basic AODV routing protocol in Route Discovery and Route Maintenance. It supports real-time traffic and solves congestion in Mobile ad hoc networks. In Route Maintenance, if any link is failed or active node is moved from the link, RODV handles the situation, by finding the alternate path between the nodes where the link is failed. This reduces the delay in transmitting the data when compared with AODV routing protocol. The routing overhead in the network is also decreased in the Ad hoc Network.

B. Hughes describes a new communication model, the space-elastic model, to provide hard real time communication by using specified geographical bounds to scope the area within which timely communication must be guaranteed in a wireless network [12]. In addition, a new location-aware real-time ad hoc routing protocol, the Space-Elastic Adaptive Routing (SEAR) protocol, is described, which provides the basis of a real-world implementation of the space-elastic model. An evaluation of the space-elastic model, using SEAR, shows that time-bounded communication is possible within the actual coverage and that time-bounded notification can be provided if adaptation occurs. However, RODV and SEAR does not consider link quality and remaining power.

3 Design RTRP for MANET

RTRP has been designed based on our previous work for wireless sensor network (WSN) which is RTLD [13]. The wireless link quality at the physical layer is studied to predict the communication between sensors. By choosing the forwarding nodes with the minimum delay limit, the network ensures real-time packet transfer in MANET. In addition, the remaining power is estimated to spread all traffic load distribution during path forwarding to the destination. In Figure 2, RTRP consists of four functional modules that include location management, routing management, power management and neighbourhood management.

3.1 Routing Management

In order to carry out this policy, RTRP calculates three parameters to select the optimal forwarding choice: packet delay that moving through one hop, PRR and remaining power (remaining battery voltage) for every one hop neighbours. The delay from the source node S to one hop neighbour N can be calculated as:

\[
\text{Delay}(S,N) = T_c + T_i + T_{pp} + T_p + T_q = \frac{\text{Round trip time}}{2}
\]  

where, \(T_c\) is the time it takes for S to obtain the wireless channel that contains carrier sense delay and backoff delay. \(T_i\) is the time to transmit the packet. It is determined by channel bandwidth, packet length and the coding scheme adopted. \(T_{pp}\) is the propagation delay, which is determined by the signal propagation speed and the distance between S and N. \(T_p\) is the processing delay, which depends on network data processing algorithms. \(T_q\) is the queuing delay, which depends on the traffic load. In a heavy traffic case, queuing delay becomes a dominant factor. Equation 1 shows that the delay between two pair of nodes is not equal because the \(T_c\) and \(T_p\) delays are not equal for all nodes. It is interesting to note that RTRP does not need synchronization timer because S inserts the transmission time in the header of request to route (RTR) packet. When N replies to S, it inserts the RTR transmission time in its reply. Thus, once S receives the reply, it subtracts the transmission time from the arrival time to calculate the round trip time.

Figure 2. Block diagram of RTRP Routing Protocol

The PRR in RTRP uses IEEE802.11b link layer at 2Mb/s. It considers Signal-to-Noise (SNR) ratio to evaluate the link quality between neighbours. Bit error rate (BER) is determined by [14]

\[
\begin{align*}
\text{BER for IEEE 802.11b at 2Mb/s} &= Q\left(11 \times \frac{SNR}{2}\right)^{1/2} \\
\text{BER for IEEE 802.11b at 2Mb/s} &= 5.5 \times \frac{SNR}{2}^{1/2} \\
\text{BER for IEEE 802.11b at 2Mb/s} &= Q\left(11 \times \frac{SNR}{2}\right)^{1/2} \\
\text{BER at 5.5Mb/s} &= 8 \times 15 \times \left[14 \times Q\left(8 \times \frac{SNR}{2}\right)^{1/2} + Q\left(16 \times \frac{SNR}{2}\right)^{1/2}\right] \\
\text{BER for 11Mb/s} &= \frac{128}{255} \times \left[24 \times Q\left(8 \times \frac{SNR}{2}\right)^{1/2} + 16 \times Q\left(16 \times \frac{SNR}{2}\right)^{1/2}\right] \\
\text{BER for 11Mb/s} &= 24 \times Q\left(12 \times \frac{SNR}{2}\right)^{1/2} + Q\left(16 \times \frac{SNR}{2}\right)^{1/2}
\end{align*}
\]  

(2)
The PRR is calculated from BER as: let $P_i$ be a Bernoulli random variable, where $P_i$ is 1 if the packet is received and 0 otherwise. Then, for $r$ transmissions, the PRR is defined by $\sum_{i=1}^{r} P_i$. Since all packets are independent and identically distributed (i.i.d.) random variables, by the weak law of large numbers PRR can be approximated by $E[P_i]$, where $E[P_i]$ is the probability of successfully receiving a packet [15]. Hence, the PRR conditioned for $m$ bits in one packet is as follows,

$$ PRR \approx (1 - P_i)^m $$

Since the average frame length for IEEE 802.11b is 1024 bytes [9], $m$ is 1024. SNR can be calculated by [16] as:

$$ SNR = \gamma(d) = P_t - PL(d) - S, $$

where $P_t$ is the transmitted power in dBm (14 dBm for IEEE802.11b), $S$ is the receiver's sensitivity in dBm (-76 dBm) [14]. $PL(d)$ is the path loss model which can be calculated as:

$$ PL(d) = PL(d_0) + 10n\log\frac{d}{d_0} + X_\sigma $$

where $d$ is the transmitter-receiver distance, $PL(d_0)$is the path loss at the reference distance $d_0$ (1 m) and is equal 41 dBm from the test bed measurement, $n$ is the path loss exponent and is estimated between 2.4 and 2.8. $X_\sigma$ is a zero-mean Gaussian distributed random variable in (dB) with standard deviation $\sigma$ (dB).

The remaining power in the battery of a mobile node is estimated in the simulation by configuration initial value of battery power. When a node sends or receives packet, its battery power decreases by a certain value. RTRP forwards a data packet to one-hop neighbour that has optimal forwarding. The optimal forwarding (OF) is computed as normalized maximum battery power, normalized minimal delay and high PRR. OF is computed in [17] as follows:

$$ OF = 0.6 \times PRR + 0.2 \times P_{batt} / P_{max} + 0.2 \times Delay / Max \_delay $$

where $P_{batt}$ and $P_{max}$ are the battery power and maximum battery power of mobile node respectively.

**Routing Problem handler**

A known problem with geographic forwarding is the fact that it may fail to find a route in the presence of network holes even with neighbour discovery. Such holes may appear due to voids in node deployment or power expiration. Routing management in RTRP solves this issue by introducing routing problem handler which has two recovery methods: fast recovery using power adaptation and slow recovery using feedback control packet.

**Forwarding Mechanisms**

RTRP uses unicast forwarding as a default forwarding mechanism. However, if an application requires better delivery ratio, geodirectional-cast forwarding will be automatically switched by setting forward mechanism bit in the configuration file. The forwarding based on quadrant can be calculated relative to the source node as in [18]. In unicast forwarding, the source node checks the forward flag of each neighbour in the neighbour table. The forwarding flag can be determined by comparing neighbour node’s quadrant with destination node’s quadrant relative to the source node. The forwarding flag is used to check the direction of neighbour node. If the forward flag is 1 (neighbour node and destination node are in the same quadrant), the neighbour node is in the direction to destination. In case of flag is 1 for any node in neighbour table, the source node will check the optimal forwarding metrics and compute forwarding progress as in equation 6. This procedure continues until the optimal forwarding choice is obtained and then the data packet will be unicast to the selected node. This procedure continues until the destination becomes one of the selected node’s neighbours. If there are no nodes in the direction to the destination, the source node will invoke the neighbour discovery.

Directional forwarding is defined as forwarding to the nodes that have the best progress towards the destination. In geodirectional-cast forwarding, if a node wants to forward a data packet to a specific destination, it broadcasts the packet to all neighbours. Then the selected neighbouring node will use unicast forwarding to forward the packet towards the destination. Therefore, if the neighbouring nodes are in the same quadrant as the destination and if the distance to the destination is less than the distance from source to destination, nodes will forward the packet using unicast forwarding. Otherwise, the packet will be ignored. Since nodes have information of its neighbours, it will not only forward but also select a neighbour that has the optimal forwarding progress towards the destination. If the destination receives multiple copies of the same packet, it will accept the first packet delivered and ignore the others. The geodirection-cast mechanism is a modification of our previous work done on Q-DIR [19].

The forwarding policy may fail to find a forwarding node when there is no neighbour node currently in the direction of destination. The routing management recovers from these failures by using routing problem handler as described in the following section.

### 3.2 Power Management

To minimize the energy consumed, power management minimizes the energy wasted by control packet overhead.

### 3.3 Location Management

The proposed location management determines localized information of mobile nodes. The network coordinate system was assumed as two dimension and the sink node is at the origin (0,0) and at least two of its neighbours are location aware. The location management is used to determine the mobile node location in MANET. It assumed that each node has a location aware mechanism such as in [19, 20] to obtain its location in the MANET area. The location mechanism
uses at least three signal strength measurements extracted from RTR packets broadcasted by pre-determined nodes at various intervals. Each pre-determined node (relay or sink) broadcasts RTR packet and inserts its location in the packet header. The distance of the unknown node from the pre-determined nodes is determined from the signal strength received based on the proposed propagation path loss model of the environment. If the distance and location of these pre-determined nodes are known, unknown nodes can trilaterate their coordinates as explained in [19, 20].

3.4 Neighbourhood Management

The design goal of the neighbourhood manager is to discover a subset of forwarding candidate nodes and to maintain neighbour table of the forwarding candidate nodes. Due to limited memory and large number of neighbours, the neighbour table is limited to a small set of forwarding candidates that are most useful in meeting the one-hop end-to-end delay with the optimal PRR and remaining power. The neighbour table format contains node ID, remaining power, one-hop end-to-end delay, PRR, forward flag, location information and expiry time.

♦ Neighbour Discovery

The neighbour discovery procedure is executed in the initialization stage to identify a node that satisfies the forwarding condition. The neighbour discovery mechanism introduces small communication overhead. This is necessary to minimize the time it takes to discover a satisfactory neighbour. The source node invokes the neighbour discovery by broadcasting RTR packet. Some neighbouring nodes will receive the RTR and send a reply. Upon receiving the replies, the neighbourhood management records the new neighbour in its neighbour table.

4 Simulation Implementation

Network Simulator-2 (NS-2) has been used to simulate RTRP routing protocol. IEEE 802.11 MAC and physical layers are used to reflect real access mechanism in MANET. Table 1 shows the simulation parameters used to simulate RTRP in NS-2. In this work, 50 mobile nodes are distributed in a random manner (150m x 150m) as shown in Figure 4. Nodes numbered as 10 is mobile source and node 18 is the sink. In the following simulation study, RTRP utilizes on demand neighbour discovery scheme. When the periodic beacon scheme is employed, data packets will transmit after 10s to allow neighbour table forwarding metrics to be initialized. It is important to note that the data packet travels between 10 and 15 hops to reach the sink. We assume the traffic used is constant bit rate (CBR). Packet delivery ratio, normalized control packet overhead and average end-to-end delay are the metrics used to analyze the performance of RTRP and the baseline (AODV and AOMDV) routing protocols. All metrics are defined with respect to the network layer. Packet delivery ratio is the ratio of packets received at the destination to the total number of packets sent from the source in a network layer. Normalized control packet overhead counts the number of control packets sent in the network for each data packet delivered while end-to-end delay is the total delay divided by number of hops between source and destination.

<table>
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<tr>
<th>Parameter</th>
<th>Value</th>
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<td>macType</td>
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<tr>
<td>Initial Energy</td>
<td>3.3 Joule</td>
</tr>
<tr>
<td>Transmission Power</td>
<td>1 mW</td>
</tr>
</tbody>
</table>

Table 1. Simulation Parameters.

In this simulation part, 50 mobile nodes are not movable. Simulation study on the influence of the forwarding mechanism is carried out using parameters configured in Table 1. The packet rates were varied from 2 to 14 packet/s and simulation time was fixed at 100s. The simulation results in Figure 4a show that the RTRP increases delivery ratio by 20% compared to the baseline. This is primarily due to its forwarding strategy which chooses the next hop that has the optimal combination of the best link quality, remaining power and minimum packet delay. In addition, Figure 4b shows the average end-to-end delay comparison between RTRP and baseline routing protocols for different packet rate. RTRP possesses short average delay compared to baseline routing protocols because it considers minimum hop-to-hop delay. Moreover, Figure 4c shows that RTRP spends less number of packets overhead compared to baseline routing protocols. This is largely due to its neighbour discovery which does not allow the one-hop neighbour to reply if it is not in the direction to the destination. Hence, the probability of collision is reduced and packet overhead is minimized. On the other hand, the baseline forwarding strategy does not consider probability of collision due to neighbour discovery which degrades the delivery ratio and energy efficiency.
4.2 Influence of topology change due to node mobility

In this simulation, 20% of mobile nodes (10 nodes) has been changed their position randomly using fixed speed which is 13m/s. Simulation study on the influence of the forwarding mechanism is carried out using parameters configured in Table 1. The packet rates were varied from 2 to 14 packet/s and simulation time was fixed at 100s. The simulation results in Figure 5a shows that RTRP experiences higher delivery ratio than the baseline protocol by 10%. This primarily due to RTPR forwarding mechanism that utilizes multipath forwarding. Figure 5b shows the average end-to-end delay comparison between RTRP and baseline routing protocols for different packet rate. Moreover, Figure 5c shows that RTRP spends less number of packets overhead compared to baseline routing protocols. This is because the baseline routing used packet broadcasting based. Packet broadcasting caused congestion and low delivery ratio specially when traffic load becomes high.

4.3. Influence of varying mobile node speed

In this simulation, 20% of mobile nodes (10 nodes) has been changed their position randomly using varying speeds between 2-20 m/s. Simulation study on the influence of the forwarding mechanism is carried out using parameters configured in Table 1. The packet rate and simulation time were fixed at 5 packet/s and 100s respectively. The
simulation results in Figure 6a show that RTRP experiences higher delivery ratio than the baseline protocol by 16%. In addition, Figure 6b shows the average end-to-end delay in RTRP is lowest than baseline routing protocols for different mobile node speed by 50%. Moreover, Figure 6c shows that RTRP spends less number of packets overhead compared to baseline routing protocols by 25%. This mainly due to RTRP utilized multipath forwarding that guarantees more packet delivery and less ETE delay.

5 Conclusion

RTRP is proposed to enhance the previous works by [6,7] in order to achieve high delivery ratio, minimum control packet overhead and minimum end-to-end delay. This paper presents a novel real-time routing protocol for MANET that selects optimal nodes based on PRR, minimum packet delay and remaining power to forward packets to the destination. In general, the finding concludes that RTRP provides high delivery ratio and spends less number of control packet overhead with minimum end-to-end delay compared to AODV and AOMDV. RTPR has been successfully studied and verified through simulation work.

References