Control Traffic Analysis of On-Demand Routing Protocol in Mobile Ad-hoc Networks

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***Abstract*—This paper presents a general model for analyzing the characteristics of routing control traffic and the influences of changing network parameters on these characteristics in mobile ad-hoc networks that use on-demand routing protocols. It provides an analytical framework for studying the features of control traffic due to mobility, node density and data traffic etc. Using this model, we found that: 1) there is an "stabilization" process in the spread of control traffic in MANETs; 2) clusters exist in mobile ad-hoc network; 3) there are backbone nodes, serving as a gateway to relay RREQ packets between different clusters. The analysis presented in this paper can be used for designing novel and efficient heuristic routing protocols for mobile ad-hoc networks.**

Keywords-Control traffic; mobile ad-hoc networks; on-demand

I. INTRODUCTION

Control traffic plays a central role in route discovery in mobile ad-hoc networks (MANETs). To carry out research on the characteristics of control traffic in MANETs when on-demand routing protocols (AODV [1] and DSR [2]) are used, involving the distribution of nodes' control packet traffic, control packets (RREQ packets) communication between nodes, the rate of RREQ packets and the ratio of the number of RREQ packets originating from one node to that of all RREQ packets relayed by this node, is of great significance to the designing of heuristic reactive routing protocols.

Over and above, great challenges remain while studying the above-mentioned characteristics of control traffic, since these characteristics are affected by many factors, such as mobility, node density and data traffic, etc. In this paper, we established a corresponding evaluation indicator for each of characteristics and gave the formula, respectively, which can provide easy access to these characteristics in MANETs at a certain time.

The rest of this paper is organized as follows. Section 2 proposes our analytical model and evaluation indicator. Section 3 describes the network model used in this paper. Section 4 presents experimental results and discussion. Finally, we have the conclusions and future work in Section 5.

II. ANALYTICAL MODEL

Control Traffic in on-demand routing protocols is mainly generated during the route discovery process. Three routing control packets used during route discovery are route request (RREQ), route reply (RREP) and route error (RERR). To experimentally determine the characteristics of control packets in MANETs, and the effects of changing network parameters, we propose the four evaluation indicator, CPT, AD, RPR and CR, and the corresponding formulas. They show different characteristics of control packets in the network respectively.

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A. Control Packet Traffic(CPT)

The purpose of indicator CPT is to reflect the distribution of control packets in a mobile ad-hoc network. And the computation formula is as follows:

$$\mathrm{CPT} = \sum_{i=1}^{n}\left(\mathrm{numCP_i}\cdot\frac{|c_i, c_0|}{R}\right)\bigg/\sum_{i=1}^{n}\mathrm{numCP_i} \qquad (1)$$

In formula (1), n is the number of nodes in the network, $\mathrm{numCP_i}$ is the number of control packets relayed by node i in Δt, c_i is the current coordinates of node i, c_0 is the coordinates of the network center [(700,700) in this paper], and R is the radio range (250m).

As gathering the network features of an instant is meaningless, we choose to examine the network features in some typical time periods during the whole simulation process. We selected 288s-312s, 684s-708s, and 1092s-1116s, all of which are 24s (Δt) long. Δt is set to 24s because each time a node arrives at a position, it will wait for 30s before the next move. For each of the three time slots, we define a time point to represent the corresponding period, T=300s, T=700s, and T=1100s respectively. To represent the node's position at time T, we use the mid-value of the position on the period's start and end timing, $c_i$namely. Rest of this paper follows the statements above.

When the number of control packets relayed by each node does not vary significantly, if CPT is higher, then most of the control packets are spread away from the center; conversely, they converge in the center. If the nodes maintain a relatively constant position, then the higher the value of CPT is, the more control packets they relay.

Additionally, if CPT is less than 1, it indicates that most of the control packets are relayed by these nodes less than one step far from c_0. There will be similar conclusions with AD, RPR and CR in the following.

B. Association Degree

Association Degree (AD) is mainly used to reflect the control packet communication between nodes. Here we only focus on the RREQ packet. There are two reasons: 1) According to the simulation, we find that control packets consist mostly of RREQ packets, nearly 80% of the control packets are RREQ packets. Therefore, RREQ packet can roughly reflect the communication situation of control packets; 2) RREQ packet plays an important role in the process of routing discovery. The more RREQ packets a node relays to its neighbor nodes, the more significant this node is. The formula of AD is as follows:

$$\mathrm{AD} = \frac{1}{2}\cdot\left\{\sum_{i=1}^{n}\sum_{j=1,j\neq i}^{n}\left(\mathrm{numRP_{i,j}}\cdot\frac{|c_{i,j}, c_0|}{R}\right)\bigg/\sum_{i=1}^{n}\sum_{j=1,j\neq i}^{n}\mathrm{numRP_{i,j}}\right\} \qquad (2)$$

$\mathrm{numRP_{i,j}}$ is the number of RREQ packets transmitted between a pair of adjacent nodes (i, j):

$$\mathrm{numRP_{i,j}} = \mathrm{RREQ}_{i\rightarrow j} + \mathrm{RREQ}_{j\rightarrow i}$$

$c_{i,j}$ is the relative average position of node i and j to the network center c_0.

For the sake of convenience, we use Blind Flooding, transmitting RREQ packets to all of the neighbor nodes.

In the case of the number of RREQ packets sent by each node doesn't change significantly, a higher AD means that most of the RREQ packets transmits are occurred relatively far from c_0, and a lower AD indicates that they are concentrated on the center area. If nodes' position is fixed, then the higher the value of AD is, the more RREQ packets they send.

C. RREQ Packet Rate

RREQ Packet Rate (RPR) is mainly used to reflect how the rate of RREQ packets is distributed in the whole network at some moment. A high RREQ packet transmitting rate means a great importance of the node in the process of routing discovery. The formula of RPR is as follows:

$$\mathrm{RPR} = \sum_{i=1}^{n}\left(\frac{\mathrm{numRP_i}}{\Delta t}\cdot\frac{|c_i, c_0|}{R}\right)\bigg/\sum_{i=1}^{n}\frac{\mathrm{numRP_i}}{\Delta t} \qquad (3)$$

$\mathrm{numRP_i}$ is the number of RREQ packets sent by node i in Δt.

In the case of the number of RREQ packets sent by each node doesn't change significantly, a higher RPR means that most of the nodes which have a high RREQ packets transmitting rate are located relatively far from c_0, and a lower RPR indicates that they are gathered in the center part. If nodes' position is fixed, then the higher the value of RPR is, the faster they send RREQ packets.

D. *Utilization Factor*

Utilization Factor (UF) describes the ratio of the number of RREQ packets originating from one node to that of all RREQ packets relayed by this node.

Those nodes with a high ratio have high routing discovery efficiency in the network.

The formula of UF is as follows:

$$UF = \sum_{i=1}^{100}\left(\frac{numROP_i}{numRP_i}\cdot\frac{|c_i, c_0|}{R}\right)\Bigg/\sum_{i=1}^{n}\frac{numROP_i}{numRP_i} \qquad (4)$$

$numROP_i$ is the number of own RREQ packets sent by node i in Δt.

III. SIMULATION MODEL

In this paper, simulations were conducted using GloMoSim 2.03 [3]. The MAC layer protocol was the Distributed Coordination Function (DCF) of IEEE 802.11 [4], and the propagation model was the two-ray ground reflection model [5].

Network zones used in the simulation was a $1400 \times 1400m^2$ square. Antenna Model was the Omni-directional model [6]. The radio bandwidth was 2Mb/sec and the radio range was 250m. The traffic was constant bit rate (CBR) and the mobility model was random waypoint [7]. CBR sources and destinations were randomly selected. Each simulation lasted for 1200 seconds. Each source waited for a random time from 60 to 100 seconds (warm-up period) before starting to send data packets, and stopped sending data packets 20 seconds (cool-down period) before the simulation ended.

Unless specified, parameter settings in the experiment are as shown in table 1.

TABLE I. SIMULATION PARAMETERS

Parameter	Value
Number of Nodes	100
Minimum Node Speed(m/s)	0.1m
Max Node Speed(m/s)	10m
Pause Time(s)	30
Number of Flows	30
CBR Rate(pkts/s)	4

IV. RESULTS& DISCUSSION

Figures 1 through 8 illustrate the distribution of control packet traffic, association degree, RREQ packets rate and RREQ utilization factor, respectively, in the case of that the simulation parameters are set as table 1 and routing protocol is AODV and DSR. In these figures, x and y represent the horizontal and vertical coordinates of one node respectively, and z is the node's number of control packet (Figure 1 and Figure 2), RREQ Packet Rate(packet/s，Figure 5 and Figure 6) and Utilization Factor (Figure 7 and Figure 8).

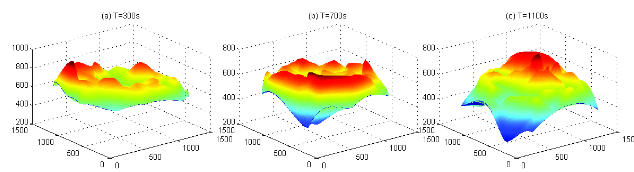

Figure 1. Control Packet Traffic of AODV

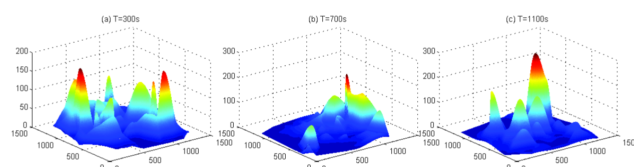

Figure 2. Control Packet Traffic of DSR

Byung-Jae Kwak recognized that the center of the network is the "hot spot" of the network in the sense that most of the relayed traffic goes through the center of the network [8]. According to Figure 1(a) and Figure 2(a), control traffic is distributed evenly in the whole network at the beginning (T=300s). After quite a long time, the control packets transmitting becomes gathered on the nodes in the central area (T=1100s, Figure 1(c) and Figure 2(c)).

Therefore, we recognize that there is an evolution process in the spread of control traffic in MANETs and call it "stabilization". Besides, there are much less DSR control packets than AODV control packets. It is mainly because DSR uses cache to reduce the number of control packets relayed.

Through the analysis of Figure 3 and Figure 4, we can draw two conclusions: 1) clustering exists in mobile ad-hoc networks, and the number of RREQ packets relayed between two nodes belonged to a same cluster is much larger than that between two nodes belonged to two different clusters. Meanwhile, association degree between the nodes in the central area is not always very high. In fact, in large networks, users may communicate mostly with physically nearby nodes; if local communication predominates, clustering would be more obvious; 2) in MANETs, there are some backbone nodes which are connected to two critical areas (viz. clusters as mentioned above). These nodes are of vital importance for the routing of the whole network. It will cost quite a lot to reconstruct such a balanced status if any of these nodes were damaged or displaced.

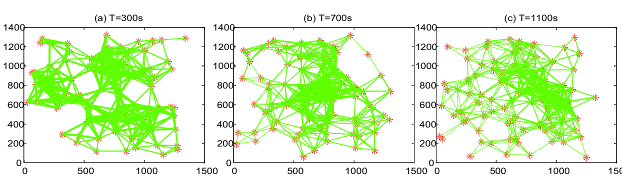

Figure 3. Association Degree of AODV

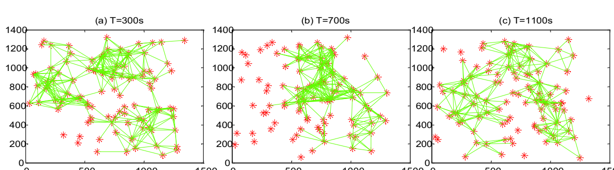

Figure 4. Association Degree of DSR

Rendong Bai claimed in [9] that RREQ packets accounted for more than 70% of total control packets. Therefore, the rate of RREQ packets is highly influenced by the distribution of control packets. In the case of routing protocol is AODV, the rate of RREQ packets is shown in Figure 5, in which we could find that its changing tendency over time is similar to the distribution of control traffic in Figures 1(a), 1(b) and 1(c). When the network reaches a stable state, these nodes with a high rate of RREQ packets are mostly located in the center part of the network. A similar conclusion can be concluded from Figure 6.

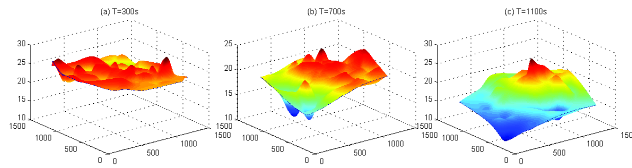

Figure 5. RREQ Packet Rate of AODV

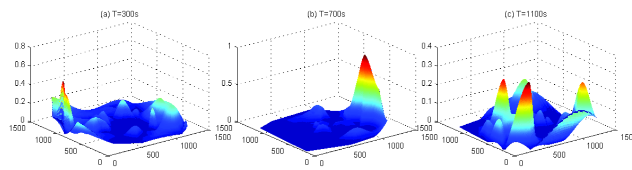

Figure 6. RREQ Packet Rate of DSR

In Figure 7 and Figure 8, a node is traffic source if its utilization factor is not zero. It can be found that the traffic sources' utilization factor is much higher when using DSR as the routing protocol than AODV. It owes a lot to caching, which DSR used for routing discovery when the load is low, thus the number of RREQ packets relayed declines.

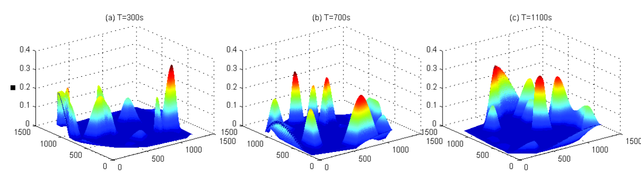

Figure 7. Utilization Factor OF AODV

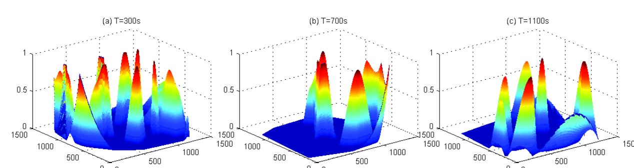

Figure 8. Utilization Factor of DSR

Now, we are going to introduce the influence of varying the number of flows, CBR sending rate, maximum node speed, and the number of nodes on CPT, AD, RPR and

UF. CPT, AD, RPR and UF of the whole network are calculated using the formula (1), (2), (3) and (4) in section 4.

A. *Varied CBR Flows*

Figures 9(a), 9(b), 9(c) and 9(d) show the results of CPT, AD, RPR and UF respectively, when the number of flows is varied from10 to 50.We observe that with increasing number of flows, UF of AODV and DSR raise rapidly. The cause lies in the fact that when network scale remains unchanged, with the increase of data flows, the number of traffic sources also grows. With the increase in traffic sources, more routes to more destinations are to be sought, hence the growth in the routing overhead of reactive protocols, and finally UF of the network increases. Additionally, we observe that the CPR, AD and RPR of AODV remain stable over time, while these of DSR increase to different degree. This mainly because DSR could benefits from caching when the load is low, however, with the rise of network load, especially when the network is under moderate and heavy offered traffic, caching becomes less efficient, thus the number of control packets explodes.

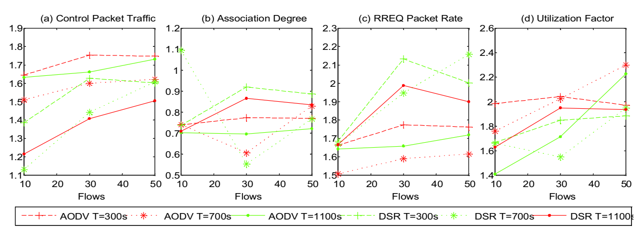

Figure 9. Performance when number of flows changes. 100 nodes, 1400×1400m^2, node speed [0.1, 10]m/s, pause time 30s.

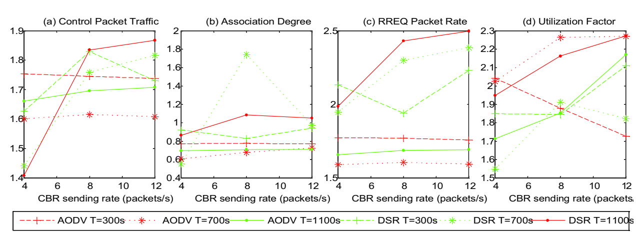

Figure 10. Performance when CBR rate changes. 100 nodes, 1400×1400m^2, 30 flows, node speed [0.1, 10]m/s, pause time 30s.

B. *Varied CBR Rate and Varied Maximum Node Speed*

Figures 10(a), 10(b), 10(c) and 10(d) show the results of CPT, AD, RPR and UF, respectively, when the CBR sending rate is varied from 4 to 12 packets per second. At different times, AODV's CPT, AD and RPR remains stable, and UF rises slowly except for at T=300s, while these indicators of DSR increase at varying rates, especially at T=1100s, when they have a huge explode. It is mainly because the number of data packets increases linearly with the rise of CBR rate, then the workload of nodes becomes heavier, and finally the packet loss rate becomes higher. Therefore, the good performance of DSR at lower loads is due to its use of caching which turns out to be too small to be of use at high loads.

Figures 11(a), 11(b), 11(c) and 11(d) show the results of CPT, AD, RPR and UF, respectively, when the maximum node speed is varied from 5 to 20 m/s. At different times, AODV's CPT, AD and RPR remains stable, and UF rises slowly except for at T=300s,while these indicators of DSR increase at varying rates, however, they decline dramatically at T=1100s. The major cause is that, as expected, as the nodes speed increases, more packets are dropped due to unavailable routes. But as the speed increase, we observe a larger drop in AODV and DSR. In low speed scenarios, as the network topology is almost constant, the routes stored in DSR cache remains constantly good and useful. But for very highly mobile network, AODV performs slightly better than DSR (after a speed of 12.5m/s in this case); DSR still relying on cache routes which are prone to be stale with increase in speed.

C. *Varied Number of Nodes*

Figures 12(a), 12(b), 12(c) and 12(d) show the results of CPT, AD, RPR and UF, respectively, when the number of nodes is varied from 100to 200. With the number of nodes increasing, AODV's CPT, AD and RPR remains practically unchanged, and UF declines slowly except for at T=300s; at T=1100s, CPT, AD and RPR of AODV drops slightly, while DSR's CPT, AD and RPR increase in varying degrees.

We attribute this to the fact that, with a higher node density, more control packets would be sent when flooding due to the exploding of neighbor nodes in routing discovery. This is due to the fact that more routing traffic is sent which results in more congestion on the network, thus the packet loss rate increases. It is quite obvious in DSR, because when a RREQ is sent, a destination replies to all RREQs it receives, and the number of control packets becomes larger, and finally aggravates congestion, whereas in AODV every destination replies to the first RREQ.

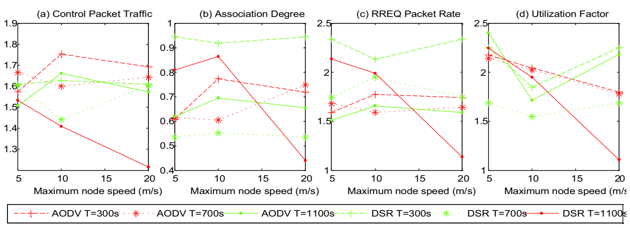

Figure 11. Performance when max node speed changes.100 nodes, 1400×1400m^2, 30 flows, min speed 0.1m/s, pause time 30s.

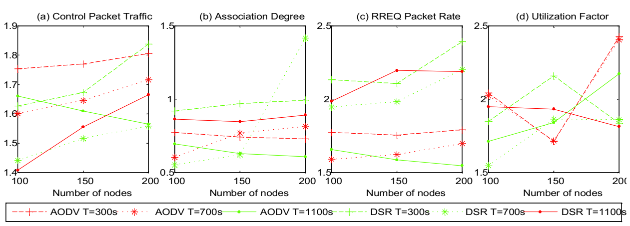

Figure 12. Performance when number of nodes changes. 1400×1400m^2, 30 flows, node speed [0.1, 10]m/s, pause time 30s.

V. CONCLUSION

This paper presents an analytical model for studying the features of control traffic in mobile ad hoc network. We proposed four analytic indicators: CPT, AD, RPR and CR, which are used to study the distribution of control traffic, control packet (RREQ packets) communication between different nodes, the rate of RREQ packets and the ratio of the number of RREQ packets originating from one node to that of all RREQ packets relayed by this node at different times, respectively.

Using this model, we found that: 1) the distribution of the control traffic is uniform during the warm up period, and while the network reaches the stabilization period, most of control traffic goes through the center of the network; 2) there are several clusters in each mobile ad-hoc network. The number of RREQ packets relayed between two nodes belonged to a same cluster is much larger than that between two nodes belonged to two different clusters; 3) there are backbone nodes, serving as a gateway to relay RREQ packets between different clusters, in mobile ad-hoc networks. The analysis presented in this paper will be used to develop heuristic routing protocols in ad-hoc networks that minimize the control traffic such as the protocol described in [10].

In the future, we plan to study the features of control traffic in vehicular ad-hoc networks, in which the nodes have a unique set of behavior characteristics, such as fixed routes, schedules, specific priorities, etc., which gives rise to distinct impact on node connectivity in the communication network, and the mobility model used in mobile ad hoc networks, for instance, random waypoint, is not adequate to represent the major characteristics of real-world vehicle motions.

REFERENCES

[1] C. E. Perkins and E. M. Royer, "Ad-hoc on-demand distance vector routing," in WMCSA '99: Proceedings of the Second IEEE Workshop on Mobile Computer Systems and Applications. IEEE Computer Society, Feb 1999, p. 90.

[2] D. B. Johnson and D. A. Maltz, "Dynamic source routing in ad hoc wireless networks," in Mobile Computing. Kluwer Academic Publishers, 1996, vol. 353.

[3] L. Bajaj, M. Takai, R. Ahuja, R. Bagrodia, and M. Gerla, "Glomosim: A scalable network simulation environment, Tech. Rep. 990027, 13, 1999.

[4] IEEE 802.11. Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications, Aug. 1999.

[5] T. Rappaport, Wireless Communications: Principles and Practice. Prentice Hall PTR, 2001.

[6] R. Ramanathan, On the performance of ad hoc networks with beamforming antennas, in: ACM International Symposium on Mobile Ad Hoc Networking and Computing (MOBIHOC), October 2001, pp. 95–105.

[7] J. Broch, D. A. Maltz, D. B. Johnson, Y-C. Hu, and J. Jetcheva, "A performance comparison of multi-hop wireless ad hoc network routing protocols," in MobiCom, 1998, pp. 85-97.

[8] B.-J. Kwak, N.-O. Song, L. E. Miller, "On the Scalability of Ad Hoc Networks: a traffic analysis at the center of a network", IEEE WCNC 2004.

[9] R. Bai and M. Singhal. Carpooling in mobile ad hoc networks: the case of multiple-target route discovery. In WiOpt 2007: 5th Intl. Symposium on Modeling and Optimization in Mobile, Ad Hoc, and Wireless Networks, Limassol, Cyprus, April 2007.

[10] J Broch, D. Maltz, D. Johnson, Y.C. Hu, and J. Jetcheva, "A performance comparison of multi-hop wireless ad hoc network routing protocols," MOBICOM '98, pp. 85-97, October 1998.