COMPONENT BASED ROUTING: A NEW METHODOLOGY FOR DESIGNING ROUTING PROTOCOLS FOR MANET

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ABSTRACT

Large variation of performance due to various environment inputs is a major impediment of implementing existing routing protocols for MANET in the battlefield. Therefore, it is a major challenge to design a routing protocol that can adapt its behavior to environment alteration. In consideration of adaptability to the environment and flexibility in protocol construction, a novel component based routing protocol methodology is proposed in this paper. Distinguished from conventional investigation of routing protocols as individual entities, this paper will firstly generalize four fundamental components for MANET routing protocols. Then, a weak component diagnosis process is proposed to improve a weak component and enhance the overall performance. Finally, preliminary simulation results demonstrate the power of the component based methodology for improving overall performance and reducing performance variation. In conclusion, the evaluation and improvement at the component level is more insightful and effective than that at the protocol level.

1. INTRODUCTION

Mobile Ad Hoc Network (MANET) have received significant research attention since the development of the packet radio networks in the 1970s. The nature of easy deployment without pre-existing infrastructure makes ad hoc networks an attraction for dynamically distributed situations comprising mobile wireless stations, such as military applications, disaster recovery and so forth. Military communication environments have been considered as the original motivation for employment of MANET, due to the requirements for battlefield survivability and convenient deployment of self-organizing infrastructures.

In recent years, increasingly widespread application of mobile Ad Hoc networks has accelerated development of mobile distributed computing. Many routing protocols have been designed for Ad Hoc networks to satisfy needs for more actively distributed algorithms. Ad Hoc routing protocols can be categorized to two major prototypes: proactive (OLSR) and reactive (AODV, DSR). These two types of protocols are characterized by the mechanism of path discovery. Proactive routing protocols constantly update the routing cache. One example of proactive routing is OLSR, which updates the routing cache by broadcasting Topology Control messages every fixed interval. The most up-to-date map of network topology is maintained in the route cache table regardless of the need for a route to a specified destination. Consequently, proactive routing protocols constantly maintain a set of available routes for all stations throughout network. Reactive (on demand) routing protocols, on the other hand, only initiate the path discovery procedure in response to a request for a route to a specified destination. No route control message will be generated until a route is required for a destination. Reactive routing protocols do not propagate routing control messages periodically, and only maintain routing entries for a subset of the entire network stations. AODV and DSR are examples of reactive routing protocols.

A number of technical papers have been published (Choi, 2004; Das, 2000; Hsu, 2003) on comparison of performance of various MANET routing protocols. Some general observations have been recognized:

a. Reactive routing protocols will perform better than proactive protocols in highly dynamic networks (Hsu, 2003).
b. Among reactive protocols, AODV outperforms DSR in more stressful situations (with higher mobility speed, with higher traffic density) (Das, 2000).
c. DSR consistently generates less routing traffic overhead than AODV (Choi 2004; Das, 2000).

Large variation in the performance of routing protocols is exhibited in the above papers. A protocol best performing in certain situations may not do so in others. None of the existing protocols can absolutely outperform all others in all possible situations. None of the existing protocols can satisfy all applications since

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different users of routing protocols may have different QoS requirements. DSR is a better choice for low control overhead, while AODV is a better choice for low packet loss ratio in high mobility. By deeply investigating MANET routing protocols, we discovered that some key functions can influence overall performance significantly. In some cases, substitution of some functions instead of entire routing protocols can improve performance significantly. Hence, selecting components from a function repository and assembling them together into a well performed routing protocol is an alternative to rewriting the entire protocol.

From the above considerations, we propose the component based routing protocol methodology with two key properties: adaptability to the environment by assembling favorite components and high flexibility in constructing plug-and-play routing protocols.

This paper is organized in the following way. The second section will introduce the architecture of the component based routing protocols, and will decompose AODV, as an example, in the framework of the architecture. In the third section, component metrics are defined for more insightful interpretation of routing performance. Finally, in section four, a weak component diagnosis process is proposed to show how to improve a weak component and enhance overall routing performance. An example shows how to decrease effectively data packet loss ratio by inserting a new component to the original DSR. Contributions of this article are four fold:

a. Introduce a novel methodology to decompose, investigate and analyze Ad Hoc routing protocols. This designing philosophy can be possibly extended to other software based protocol suites.

b. Justify the definition of components. This work provides a framework for decoupling complicated Ad Hoc routing protocols into parts for easier understanding.

c. Present detailed metrics to evaluate component performance under various environments. This provides more insightful understanding for routing protocol performance.

d.“Significant component” and “weak component/subcomponent” are introduced to provide a unique perspective for routing performance investigation and performance evaluation.

e. “Weak component diagnosis” is designed to locate significant component and weak component. Simulation results prove its effectiveness on enhancing overall performance.

2. ARCHITECTURE OF COMPONENT BASED ROUTING PROTOCOLS

Component based routing protocols is a new paradigm for network modeling, design and study. In conventional research studies, routing protocols are always studied as a whole entity. However, for component based methods, we investigate components (units of routing protocols) instead of the entire routing protocols. The component based routing protocol methodology ensures component functionality reusable in new and innovative contexts. If planned strategically, the component based routing protocol can be highly adaptive to various implementation scenarios. There are several challenges for the design of component based routing protocols. The first one is to define components and decompose routing protocols into systematic components. The second one is to evaluate the performance level of each component in different contexts and make it a reference for component selection. The other challenges are how to translate performance requirements to the selection of components and assembly isolated components together.

It is not straightforward to decouple routing protocols into well-defined components. This framework needs to be flexible enough to accommodate existing routing principles, functionalities and protocols, as well as new developments in the future. As such, we propose a framework for abstracting, identifying and organizing components for ad hoc routing protocols.

The hierarchical architecture of component based routing protocols is introduced below (Baras, 2005):

1. Definition of components: Component is a fundamental abstraction that applies to many physical structures such as physical parts of a machine, structures of a software objects. The concept of component proposed here is to define nonphysical objects: behaviors of routing protocols. No structures such as route cache table, neighbor list or packet format will be expressed by components.

Although different Ad Hoc routing protocol have different route discovery mechanisms, some common constituent functionalities are shared among various Ad Hoc routing protocols. We synthesize the common functionalities and categorize them into four components: *path discovery component*, *topology database maintenance component, route maintenance component* and *data packet forwarding component*. Each component is well defined according to their functionality and cooperates with other components to achieve the task of routing.

2. Specification of subcomponents: Subcomponents are component’s units, which are required to realize functional components of protocols. Irreflexivity and antisymmetry are two primitive principles for definitions of subcomponents. Irreflexivity defines that a component can’t be a subcomponent of itself. Antisymmetrity states that two components can't be subcomponents of each other. A component can have different subcomponents in different protocols. For instance, in the Path Discovery Component, routing paths can be searched in a hop based method (AODV) or a path based method (DSR). We define them as Hop_based_RREQ and Path_based_RREQ respectively.

3. Identification of Physical Structures: Physical structures are requested to implement methods for routing functions. In routing protocols, physical structures are categorized into local database and packet formats. The examples of local database are routing table, route request table, local connectivity table, send buffer and maintenance buffer. Packet formats are employed to carry and disseminate link or path information. The detailed formats of physical structures are decided by what kind of information needs to be stored, and what is the index method for the stored information. The physical structures will interact with subcomponents, and the information stored in physical structures can be modified by action of component's methods. Before defining physical structures, the requirements for subcomponents need to be considered.

The hierarchical structure and their interaction are illustrated in the Fig. 1.

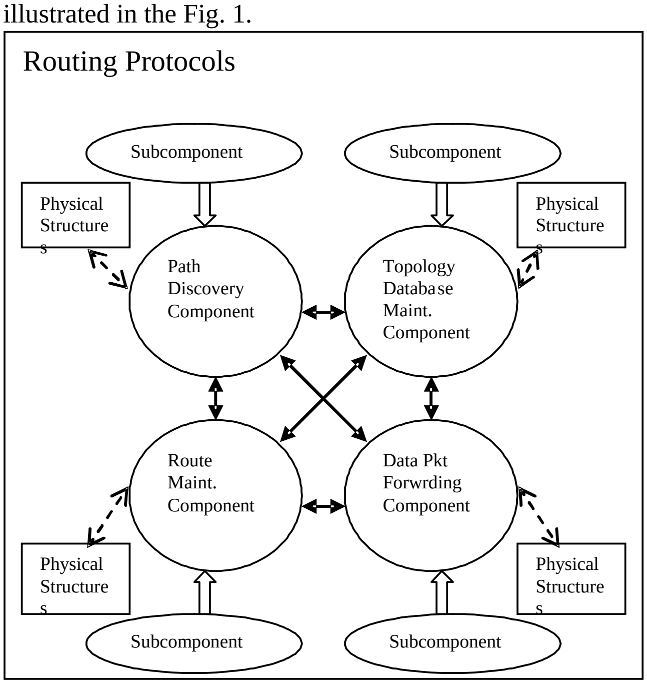

Fig 1. Hierarchical component structure

3. PERFORMANCE METRICS FOR COMPONENTS

Classical metrics for overall performance, data packet loss ratio, routing control overhead and end to end delay for a MANET routing protocol are not suitable for the analysis for component performance. Meaningful metrics are also crucial for performance evaluation and comparison of subcomponents. Finer metrics are better for component evaluation.

1. Metrics of Route Discovery Component

1.1. Percentage of Path Discovery Success: #RREQ Replied / #RREQ Initialized. It's an assessment of effectiveness of the path discovery component. The higher the rate, the more efficient the path discovery.

1.2. Path Discovery Inefficiency Factor:
#Total Path Discovery Traffic Rcvd / #RREQ generated. The less this the value, the more efficient is the path discovery.

1.3. Percentage of Route Cache Hit for Data Packet:
#Cache Hit Data Packet from High Layer / #Total Data Packet from High Layer. This is the measure of effectiveness of the path discovery component with respect to its capability of obtaining bypass paths. Bypass paths are byproducts of the path discovery component; paths captured during path discovery that lead to destination stations besides target stations.

1.4. Percentage of Cached RREP:
#Cached RREP Generated / #Total RREP Generated. It is an assessment of efficiency of the subcomponent Cached_RREP.

1.5. Average Delay for Path Discovery:
Accumulated Path Discovery Delay / #RREQ Replied. It is a measure of latency of the path discovery component. How fast can the path discovery component be completed on average?

1.6. Path Discovery Control Overhead
#Total Path Discovery Traffic Rcvd / #Total Data Packet from High Layer. This is a measure of control overhead for each data packet generated by the path discovery component.

2. Metrics of Route Maintenance Component

2.1. Percentage of Data Packet Reaching Destination Aided by Route Maintenance:
#Data Packet Reaching Destination Aided by Route Maintenance / #Data Packet Reaching Destination. It is a measure of the importance of route maintenance during path repairing.

2.2. Average Overhead of Route Maintenance:
#Total Control Traffic Introduced by Route Maintenance / #Data Packet Reaching Destination Aided by Route Maintenance. This assesses control overhead introduced by route maintenance.

2.3. Percentage of Route Maintenance Success:
#Data Packet Reaching Destination Aided by Route Maintenance / #Data Packet Attempting Route Maintenance. It measures efficiency of route maintenance.

3. Metrics of Packet Forwarding Component

3.1. Percentage of Forwarding Failure:

#Data Packet Forwarding Failure between Hops / #Data Packet Forwarding between Hops. This measures efficiency of data packet forwarding. The lower the rate, the better the performance of data packet forwarding.
3.2. Average End to End Delay for Packet Forwarding: Accumulated End to End Delay / #End to End Data Packet Forwarding. It is a measure of latency of data packet delivery.

4. Metrics of Topology Database Maintenance Component:
4.1. Overhead of Topology Database Maintenance:
Total Control Packet Traffic Introduced by Topology Database Maintenance / #Data Packet Reaching Destination. This measures control overhead introduced by the topology database maintenance component.

As illustrated in the example below, component metrics are crucial for interpreting overall routing performance. In Fig.2, under all mobility speeds, DSR has a pretty higher cache hit ratio than AODV. This is the major reason for lower control overhead of DSR than AODV. Path discovery process can be saved for cached routes stored in the route cache table. However, there are disadvantages. This dependence on cached routes is a key reason for high packet loss ratio. Especially for networks with rapidly changing topology, stale cached routes cannot be deleted in time and pollute all other route cache tables throughout the entire network. When nodes learn a stale path, and use it to forward data packets, it will be more difficult for data packets to hear Acknowledgement from next hop, since network topology is already changed and the next hop is not reachable. Thus, DSR usually has higher data packet loss ratio than AODV. We will propose an ıprovement method for DSR to decrease data packet ss ratio in the next section.

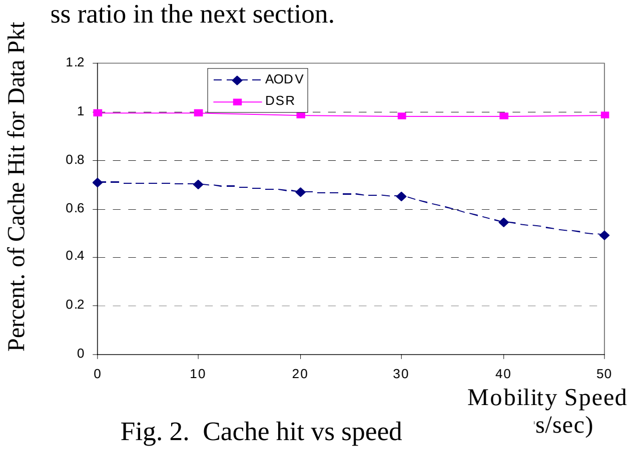

Fig. 2. Cache hit vs speed

4. WEAK COMPONENT DIAGNOSIS

It is believed that overall routing performance, in terms of packet throughput, packet loss ratio, end-to-end delay and routing overhead, can be projected to individual component's performance. Furthermore, the routing protocol's performance can be improved by replacing some weak component without replacing the entire routing protocol. Therefore, the key problem is how to detect a weak component that deteriorate overall routing protocol performance. A scheme called weak component diagnosis is designed for weak component detection. In this scheme, *the first step* is to detect a significant component, which has the most contribution to the overall routing performance. *The second step* is to investigate the significant component carefully and find out which component or subcomponent is the weak part that takes responsibility for bad performance. *The third step* is to improve the weak component to obtain better performance for significant components. In the end this process improves the entire routing protocol's performance.

4.1 Performance Projection

The most *significant component* is defined as the component which has the largest effect on the overall performance. A routing protocol is considered as a system of components and sub-components. The routing protocol's performance is the accumulated effect of components' performance. This accumulating effect can be assessed quantitatively by performance metrics. How to evaluate each component's contribution to the value of performance metrics? Performance projection is presented here to resolve this problem.

Let's consider overall performance metrics one by one. First, for packet loss ratio, the packet loss can occur in the "send buffer" while waiting for RREP, this is the portion of packet loss ratio that happens in the path discovery component. And packets can also be dropped in the "maintenance buffer" while waiting for Acknowledgement for confirming next hop's reachability (in DSR). This part of packet loss is contributed to the route maintenance component. In AODV, packet loss can occur in the data packet forwarding component. Hence, the overall performance metric of Packet Loss Ratio can be projected onto three parts: Path Discovery Component, Route Maintenance Component and Data Packet Forwarding Component. Second, for end-to-end delay, the delay can be incurred in the path discovery component, route maintenance component and data packet component. Third, routing control packets can be generated by the path discovery component, the topology database maintenance component and the route maintenance component.

After decoupling the value of overall performance to different components, we need a quantitative measure for the contributions of each component. To record detailed numbers related to each component's contribution, a packet registration table is developed.

To consider end-to-end delay, latency will occur whenever a data packet is stored in some intra-component interface (send buffer, maintenance buffer). The time spent on waiting in interfaces will be recorded, and be used to compute a percentage to the total end-to-end delay. For instance, in DSR, a data packet from an upper layer will first search the route cache table for existing routing paths to its destination. If the path doesn't exist there, the path discovery component will start to work, and the data packet will be stored in the send buffer and wait for RREP. Upon receiving RREP, the packet will be released from the send buffer. The packet will be traced, and we record the accumulated time spent waiting for RREP as t (P) in the packet registration table. After being released from the send buffer, the data packet will be copied into the maintenance buffer, and wait for an Acknowledgement from the receiving node to confirm the next hop's reachability. If the Ack can't be heard by the end of a timeout, the copy of the data packet will be sent out, and still wait for the Ack, until either the maximum number of retransmissions is reached, or the expiration time of the maintenance buffer is reached, whichever happens first. We trace the data packet and record the accumulated time spent in the maintenance buffer as t (M) in the packet registration table. When the data packet reaches its destination, the end-to-end latency is computed as t (E). So the percentage of delay contributed by each component is computed as bellow:

Ratio of path discovery delay to EtE delay = t (P) / t (E)
Ratio of route maintenance delay to EtE delay = t (M) / t (E)

Some simulation results will demonstrate how each component's contribution to end-to-end delay is changed by simulation scenarios. Below, simulations are performed by OPNET (opnet, 2006). 20 mobile stations move in a field of 2km x 2km. The simulation will study performance at different mobility speeds of 0, 15, 30 meters per second. The Traffic model implemented is Data Traffic (640 bits/sec), Voice Traffic (2560 bits) and Video Traffic (20480 bits/sec). Routing protocol is AODV.

As shown in Fig. 3, when mobility speed is increased, the Path Discovery Delay has higher proportion of End to End Delay. In Fig. 4, at the same mobility speed, the higher the data traffic density, the higher the ratio of Path Discovery Delay to End to End Delay. Therefore, for a high mobility speed network and high traffic density network, the Path Discovery Component is a significant component which needs to be investigated carefully to obtain possible improvement schemes for decreasing EtE delay, since path discovery delay is a major portion of EtE delay for high mobility speed and high traffic density networks.

From simulation results, performance projection is very effective for locating significant components. By projecting overall performance to different components, we can easily detect significant component that contribute most to the performance. This method provides us a better perspective than protocol level for which part of the protocol take the most responsibility and has the large space for performance improvement.

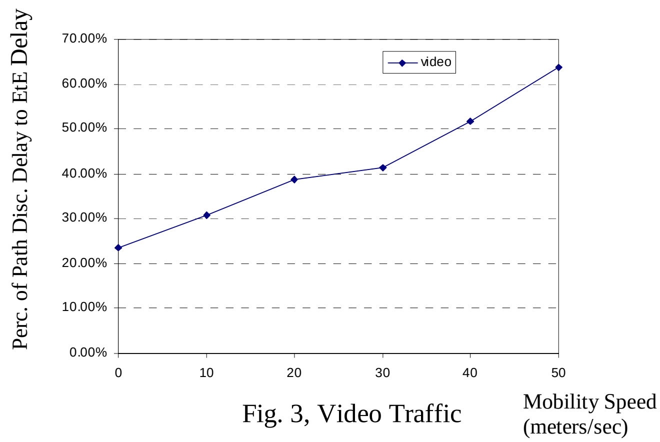

Fig. 3, Video Traffic

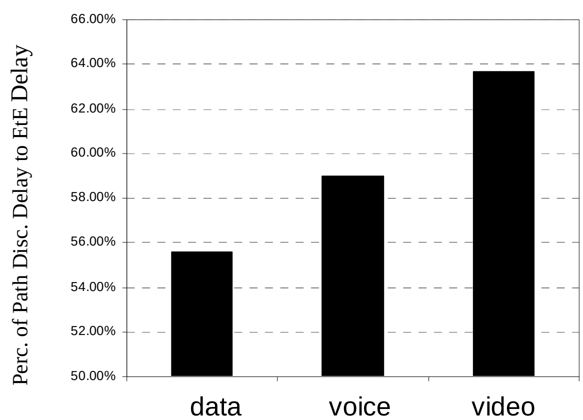

Fig. 4, Mobility Speed 50 meters/sec

4.2 Investigation of Weak Component

After locating a significant component, we have to carefully investigate the significant component to find out which subcomponent or component is responsible for the bad performance of the significant component. Replacing the weak component or weak subcomponent can improve performance of the significant component, and consequently lead to better performance for the overall routing protocol.

Up to now, although many routing protocols have been designed for mobile ad hoc network, none of them can maintain high performance under all situations. Large variation of performance of routing protocols is exhibited. Additionally, none of the existing protocols can satisfy all applications since different users of routing protocols may have different performance expectations. DSR is a better choice for low control overhead property, while AODV is a better choice for low packet loss ratio in high mobility situations. Hence, a more adaptive routing protocol is desired for reducing performance variance and different environment inputs and QoS inputs. By deeply investigating MANET routing protocols, we discovered that some key functions can influence overall performance significantly. In some cases, substitution of some functions instead of entire routing protocols can improve performance significantly. Hence, how to detect a weak component and replace it by a more efficient component is a key problem to be resolved for constructing component based routing protocols.

Below we provide an example to show the effectiveness of replacing a weak component. Simulation results will show that changing or inserting a component (subcomponent) can improve overall performance.

In the case below, DSR will be performed for three traffic modes: Data Traffic (640 bits/sec), Voice Traffic (2560 bits/sec) and Video Traffic (20480 bits/sec). Simulation is performed under mobility of 0, 10, 20, 30, 40 and 50 meters/second. We are trying to detect a significant component for packet loss ratio and replace a weak component to decrease packet loss ratio. By tracking each data packet and monitoring the intra-component interface, *the percentage of packet loss due to path discovery component is 0*, and the *percentage of packet loss due to route maintenance is 1*. Therefore, the route maintenance component is the significant component which takes all responsibility for packet loss ratio. As a result, we'll focus on investigating the route maintenance component and try to develop a scheme to improve the performance of route maintenance component and decrease packet loss ratio.

To figure out the weak component, let's first review DSR's working mechanism for the route maintenance component. In DSR, after RREP is received, the data packet will be copied to an intra-component interface: maintenance buffer. And the sender of the data packet will send an Ack-request to next hop which will be used to relay the data packet. After receiving the Ack-request, the next hop will send an Acknowledgement to the sender. If the sender can receive the Ack within timeout, the copy of the data packet will be destroyed. Otherwise, the data packet will be resent with an Ack-request message until the maximum number of retransmissions is reached. When the maximum number of retransmissions is reached, the data packet will be discarded.

Since DSR has a pretty high cache hit ratio (shown in Fig. 2), the controlling overhead remains low because path discovery process can be saved for cached routes stored in the route cache table. However, there are disadvantages. This dependence on cached routes is a key reason for high packet loss ratio. Especially for networks with rapidly changing topology, stale cached routes can't be deleted in time and pollute all other route cache tables throughout the entire network. When nodes learn a stale path, and use it to forward data packets, it will be more difficult for the data packet to hear Acknowledgements from the next hop, since network topology is already changed and the next hop isn't reachable. After investigating the mechanism of the route maintenance component of DSR, we understand that some mechanism for deleting stale cached routes containing dead neighbors is required to decrease DSR's packet loss ratio. In this case, *the significant component is the route maintenance component*, and the *weak component is the topology database maintenance component*.

4.3 Replacement of Weak Component

To reduce the data packet loss ratio, we introduce a Topology Database Maintenance component to help detect dead neighbors, and delete cached paths including the dead neighbors to keep cached paths up to date. Each node will broadcast a Hello message at an interval T (hello). And each node will maintain a neighbor list which records the latest update time for each neighbor. If a neighbor on the neighbor list can't be heard by the node before a timeout, the neighbor will be deleted from the neighbor list, and all cached routing paths, which include the dead neighbor, will be removed from the route cache table. This Topology Database Maintenance component is borrowed from AODV. The activity diagram is shown in Fig.5.

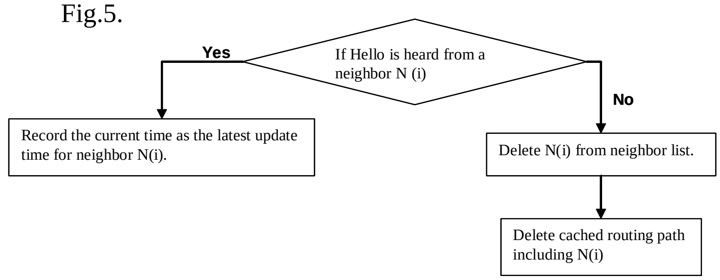

Fig.5, Activity Diagram for Topology Database Maintenance Component

In order to show the improvement on performance directly, we measure the data packet received ratio instead of the data packet loss ratio. As shown in Fig. 6, the data packet received ratio is decreasing along with the mobility speed, and decreasing along with traffic density. So, with the same mobility speed, video's packet received ratio is the least, voice's packet received ratio is in middle, and data's packet received ratio is the largest.

After inserting the new component into the DSR routing protocol, the data packet received ratio is raised effectively as shown in Fig. 7. As compared to Fig. 6, the slope of packet received ratio curve is steadier in Fig. 7. Therefore, for the same traffic mode, the variation of packet received ratio is decreased under different mobility speed scenarios.

By comparing the improvement ratio for data packet received ratio at different traffic densities, it is shown that video traffic has the largest improvement ratio most of the time.

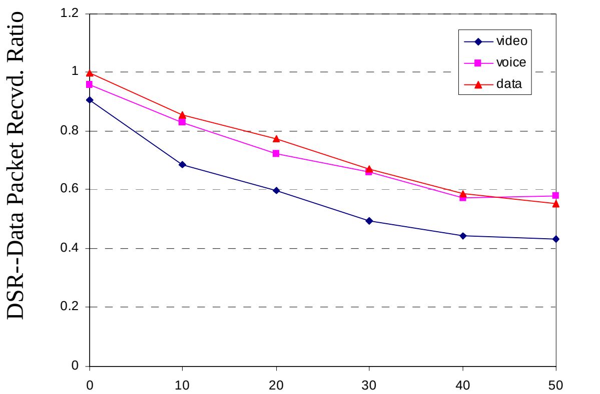

Fig. 6

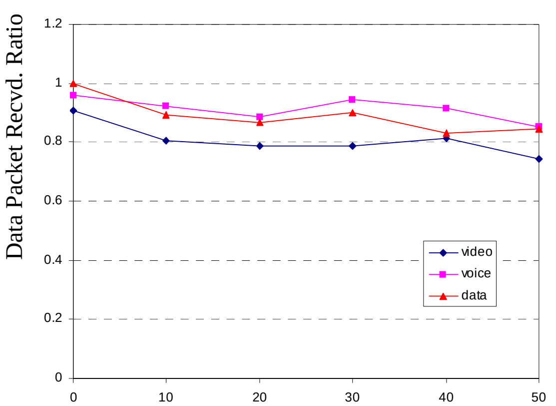

Fig. 7

Improvement ratio = (packet received ratio with improved DSR – packet received ratio with original DSR) / packet received ratio with original DSR

The improvement is larger for faster mobility and higher traffic density. This improvement is crucial for damping performance variance under different mobility modes and traffic modes. As shown in Fig. 7 and Fig. 8, by only inserting an extra component, the data packet received ratio can be increased by an average of 43.67% for video traffic, 30.53% for voice traffic and 24.17% for data traffic. This is a good example to show how to select the significant component and the weak component and how to replace the weak component to improve the overall performance.

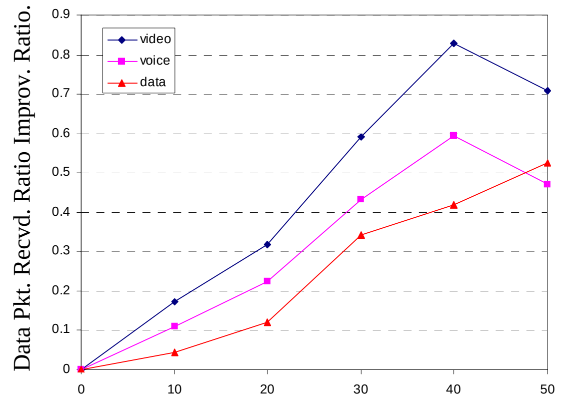

Fig. 8

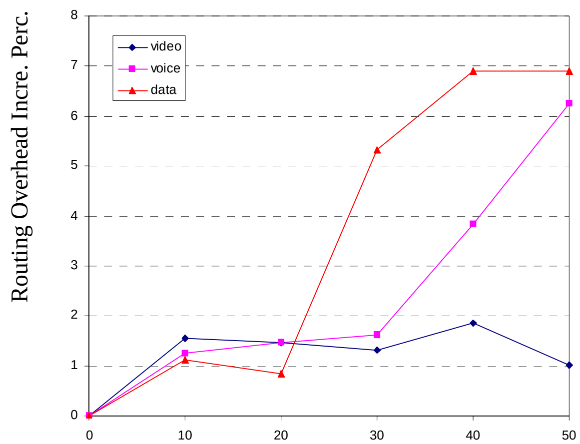

Fig. 9

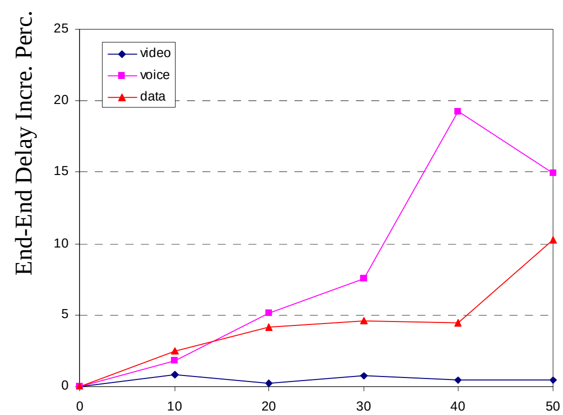

Fig. 10

After improving DSR by implementing Hello messages, besides recording the packet received ratio improvement percentage (Fig. 8), we also compute statistics for the routing overhead increment ratio (Fig. 9) and the end to end delay increment ratio (Fig. 10).

As shown in these figures, all three traffic modes make improvements for the data packet received ratio by sacrificing routing control overhead and end to end delay. However, this compromise is endurable under some scenarios. It is observed that video traffic has the least increment for controlling overhead and EtE delay under mobility scenarios higher than 20 meters/sec. Furthermore, video traffic has the least variance on changes of control overhead and EtE delay. Intuitively, we can conclude that for video traffic expecting low data packet loss ratio, the improved DSR is preferred. And for mobility speed less than 20 meters/sec, voice traffic and data traffic both have endurable increment ratio for controlling overhead and EtE delay. Hence, voice and data traffic under low speed (< 20 meters/sec) can generate better packet received ratio without deteriorating the other two performance metrics.

CONCLUSIONS

To better understand MANET routing protocol beyond protocol level, in this study, we propose a component based methodology for routing protocol design. In conventional studies of Ad Hoc routing protocols, we analyze the overall routing protocol as an entity. However, in this article, we're trying to understand the contribution of different components to the overall routing protocols. By implementing weak component diagnosis and replacing the weak component, we achieved much lower data packet loss ratio, thus improving the original DSR protocol. Investigating simulation results, we have learned the two lessons below:

1. It is more insightful to observe performance metrics at the component level than at the protocol level. Routing protocol's performance results are accumulated effects of all components. Performance projection provides us a quantitative measure of how each component contributes to overall performance. The component that has the most contribution is defined as the significant component, and will be investigated for enhancement. Replacement of the weak component, instead of changing the entire routing protocol, can achieve great improvements for some overall performance. This is an encouraging result that shows the applicability of component based methodology.

2. As application tailored protocols, component based routing protocols, should provide the user with a good interface to select the favorite composition of components. Different users of routing protocols have different expectations for routing performance. Some users will put emphasis on packet loss ratio, while others may request low routing control overhead. When comparing different composition of components, how to rank compositions according to different multicriteria? Therefore, a ranking method is required to compare different composition and help selecting a composition. This ranking method must have the following characteristics: low computational complexity, adaptive to QoS, minimal simulation settings. This will be the major concern in our future research.

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