Distributed Architecture with Control Scheme and Status-aware Routing Protocol for QoS Support in MANETs

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Abstract—In this paper, we propose a distributed architecture to provide quality of service (QoS) for mobile Ad hoc networks (MANETs). The proposed architecture includes two major approaches: distributed control scheme and status-aware routing protocol, both of which are implemented in a fully distributed manner which do not need resources allocation or reservation at the intermediate nodes. Meanwhile, we analyze an intra-flow interference model to estimate the available bandwidth for control scheme in MANETs with the contention-based Media Access Control (MAC) layer, and explore the status of the remaining power capacity as well as the traffic load at each node to select the best reliable route. Simulation results show that the proposed architecture can significantly improve the end-to-end delay performance for real-time traffic and extend the network lifetime under different traffic load conditions.

Index Terms—Distributed architecture, control scheme, routing protocol, quality of service, mobile Ad hoc networks, available bandwidth

I. INTRODUCTION

Mobile Ad hoc networks (MANETs) have attracted a lot of attention because of their distributed, wireless, and self-configuring properties [1]. These features make it possible to exchange information in various situations and create many opportunities for MANETs, with the growth of multimedia services, providing Quality of Service (QoS) guarantees for real-time applications has become a necessary part in the design of MANETs. However, the inherent features including dynamic topology, unstable wireless links, and limited energy capacity in such a network present big challenges for providing appropriate QoS guarantees.

A lot of researches on designing efficient schemes to support QoS for MANETs have been going on. The major issues include QoS models, connection admission control, routing, Media Access Control (MAC), and resources reservation etc.

II. RELATED WORK

Providing QoS support in MANETs may be faced with several problems [2], such as shared natures of the wireless medium, node mobility, and unreliable wireless channel. Many research works [3]–[5] are in progress to resolve them, and in this section we will summarize the related works.

A number of QoS routing approaches have been discussed in the literatures. According to the route selection schemes there are mainly two categories: source based QoS routing and
hop-by-hop QoS routing [6]. The first class [7], [8] locally estimates the path availability without the route determination executed at any intermediate node. The second one [9] intends to share the task of route selection among the nodes on the path from the source to the destination, aiming at improving network scalability.

Studies and proposals in [10]–[12] address the admission control in QoS guaranteed MANETs. For example, Contention-aware Admission Control Protocol (CACP) [10] presents three methods to achieve the contention-aware admission control on a single channel by using local and c-neighborhood available bandwidth. Similarly, Perceptive Admission Control (PAC) [11] tries to avoid congestion by reserving a small portion of the bandwidth, but it incurs lower resource utilization. As demonstrated in [12], Adaptive Admission Control (AAC) uses the combination of intra-flow contention, mobility, and carrier sensing to minimize the complexity and control overhead.

Authors in [13] have compared two different methods to estimate bandwidth: “Hello” bandwidth estimation and “Listen” bandwidth estimation. A node-based proposal [14] attempts to estimate the remaining bandwidth between two neighbor nodes on a per-node basis in IEEE 802.11 Ad hoc networks, furthermore, the scheme in [15] combines medium state monitoring, probability of collision estimation, and backoff time as a whole to improve the method in [14].

Our first scheme in the proposed architecture is based on the Stateless Wireless Ad hoc Networks (SWAN) model [16], which performs the source-based admission control for real-time traffic and the local rate control for best-effort traffic. The second one adapts to the status of each node to determine the best reliable route and prolong the lifetime of the whole network. The combination of the two schemes could not only reduce the average delay for real-time traffic, but also improve the lifetime for MANETs. In addition, the proposed architecture is flexible to be implemented.

III. DISTRIBUTED ARCHITECTURE

As illustrated in Fig 1, the distributed architecture at each node consists of two major parts: data panel and control panel. The data panel which follows the basic layered network structure is capable of passing data message through different layers, and the status-aware routing protocol runs on this panel as well. The control panel realizes the functions of admission control, data rate control, and the interaction of the signaling. Based on the existing MANETs, the QoS related approaches in the proposed architecture could be designed independently and implemented locally at each node.

A. Distributed Control Scheme

The control scheme, which specifies the admission control for the real-time traffic and the data transmission regulation for the best-effort traffic, exists in the control panel mentioned above and is the key part of the proposed architecture. The admission control for a new flow is only conducted at the source node, and the intermediate nodes do not need to maintain any per-flow information. During the control process, source node measures the “bottleneck bandwidth” on the path from the source to the destination, and then determines whether the available resources can meet the requirements of a new flow while still maintaining bandwidth levels for existing flows. The rate control is implemented at each node along the path according to the packet delay of the MAC layer which can reflect the network congestion status.

Fig.1. Distributed architecture

The proposed control scheme depends on the estimation of the available bandwidth at each node on the path, which can be solved from the information of MAC layer and gathered by the admission controller in the control panel at the source node via the request and response probe packets described in [16]. In order to get the hop counts on a path, our proposal modifies the probe packets by adding a “hop count” field to record this value which is necessary for predicting of bandwidth consumption, and the detailed analysis is presented in section III B. Furthermore, the sliding window scheme is used to eliminate the influence of temporary changes on the wireless link (such as small scale fading) to obtain a smoothed value, which can be expressed as below:

\[
B_i'(n) = \lambda B_i'(n) + (1 - \lambda)B_i(n-1)
\]  

where \(B_i(n)\) is the measured available bandwidth of node \(i\) at time \(n\), \(B_i'(n)\) is the smoothed available bandwidth, and \(\lambda\) is a coefficient between 0 and 1. A larger \(\lambda\) value makes the \(B_i'(n)\) more sensitive to the current \(B_i(n)\).

B. Prediction of Available Bandwidth

To make the admission control more efficient, the resources consumed by a new flow must be evaluated accurately, especially for the contention-based 802.11 MAC layer. However, due to the shared feature of the wireless channel, the nodes belonging to the same multi-hop path will contend to
access the channel simultaneously for transmitting the packets belonging to the same flow, in other words, there will be interference among the nodes serving for the same flow, so we call it intra-flow interference here[17]. As shown in Fig.2, a flow at the rate of \( B_f \) is transmitted along the path from node A to node E, and we take node C to explain the effect of intra-flow interference.

![Fig.2. Intra-flow interference example](image-url)

Since node A is within the carrier-sensing range of node C, during the period of the transmission from node A to node B, node C could receive the Clear to Send (CTS) message from node B and then keeps silence, which means the available bandwidth of \( B_f \) at node C has been consumed by node A. Similarly, node C is the exposed node of node D, during the transmission from node D to node E, node C could receive the Request to Send (RTS) message from node D and then keeps quiet, and that means the transmission from node D to node E also decreases the available bandwidth at node C by \( B_f \). In addition, the other two hops of this single flow between node B and node C, node C and node D will consume the bandwidth of \( B_f \), respectively. As a result, the bandwidth consumed by this flow at node C is \( 4 \times B_f \), so taking the intra-flow interference into consideration, the bandwidth consumption \( B_c \) caused by a flow of rate \( B_f \) with \( N \) hop can be formulated as:

\[
B_c = \begin{cases} 
N \times B_f & N \leq 4 \\
4 \times B_f & N > 4 
\end{cases}
\]  

(2)

When the bottleneck bandwidth \( B_b \) from the source to the destination is obtained by using probe packets, the operation of the admission control at source node is presented as below:

- if \( B_c \geq B_b \)
  - reject the new flow;
- else
  - accept it and send it’s packets directly to the routing layer.

C. Network Status-aware Routing Protocol

The proposed status-aware routing protocol existing in the data panel is based on the conventional Ad hoc on-demand distance vector routing protocol (AODV) [18] which is one of the reactive routing protocols for MANETs. Because of its dynamic route discovery and efficient route establishment without periodic routing updates, AODV is suitable for bandwidth constrained applications, and here it is adopted in the proposed architecture. In the proposal we modify the route discovery phase of AODV according to the local network status and develop a novel delayed rebroadcast scheme to protect the nodes with little remaining energy, or to avoid the congested nodes as well.

In our scheme, the intermediate node delays the forward of the route request (RREQ) message for a period \( T_d \). The smaller \( T_d \) means the earlier RREQ is rebroadcast from this node, so the RREQ passing through this node might reach the destination earlier than others. Since the destination replies a route reply (RREP) message as soon as receiving the first RREQ, the path with the smallest total \( T_d \) could be selected out. One node with more energy and less buffered packets could have a higher probability to rebroadcast the RREQ packet, and the route including this node could be selected for data transmission at a higher rate. In our scheme the \( T_d \) is expressed as:

\[
T_d(n) = \left[ \alpha E_0^i / E_r(n) + \beta B_m(n) \right] T_0
\]  

(3)

If node i needs to rebroadcast a RREQ message which is the \( n^{th} \) packet arriving, \( T_d \) will be updated by the formula (3), where \( \alpha \) and \( \beta \) are coefficients bounded between 0 and 1. A larger value of the coefficients means the related aspect could have greater effect on the route selection. \( T_0 \) is a normalized delay time, and it takes a smaller value when the network is sparse, but takes a larger one when the network is dense.

The remaining power capacity \( E_r(n) \) is formulated as:

\[
E_r(n) = E_0^i - \sum_{k=1}^{n} P_k^i T_k^i
\]  

(4)

\( E_0^i \), \( P_k^i \), and \( T_k^i \) denote the initial power capacity of node i, the transmission power and the time it takes to transmit the \( k^{th} \) packet, respectively.

Meanwhile, each node periodically checks the occupancy of its MAC layer buffer. The traffic status \( B_m(n) \) could be evaluated by the ratio of the number of packets currently queued \( N_w(n) \) to the buffer size \( N_b \), so the formula is given as:

\[
B_m(n) = N_w(n) / N_b
\]  

(5)

IV. SIMULATION RESULTS AND ANALYSIS

The simulation is operated to compare and analyze the
performance of the proposed architecture with the conventional system which do not provide QoS support. In this section, we use DC-SA-AODV (Distributed Control and Status-aware AODV Routing Protocol) to denote our distributed architecture, and N-AODV to denote the system that without QoS implements, respectively. The network consists of 20 nodes in a 600m×800m rectangular field, and the random waypoint is used as the node mobility model with the speed of 4m/s. The MAC layer is based on IEEE 802.11 standard with 2Mbps data rate and the radio range is 120m. An interface queue at the MAC layer could hold 256kbits.

In our simulation scenarios, source nodes generate packets at constant bit rate (CBR) to illustrate different traffic loads, and the data length is fixed to 512 bytes. The performance metrics for evaluating our work include end-to-end delay of real-time traffic, throughput of best-effort traffic, and network lifetime.

Fig.3 shows the average end-to-end delay performance of real-time traffic with the growing traffic injected into the network. In this scenario, simulation duration is set to 300 seconds, the source nodes generate packets at the rate of 20, 40, 50, or 60 packets per second, and the ratio of the number of best-effort packets to the total packets is fixed to 50%. As shown in Fig.3, both in a network with little traffic and in a network with higher load, the average end-to-end delay for real-time traffic is below 50 milliseconds when the network running steadily.

![Fig.3. Average end-to-end delay of real-time traffic](image)

Especially, when the packets generation rate is smaller than 50 packets per second, the end-to-end delay is well kept less than 30 milliseconds. This thanks to the control scheme that accepts the real-time traffic only if the network resources could meet the QoS requirements.

The impact of increasing real-time traffic on the throughput of best-effort traffic is illustrated in Fig.4. In this scenario, we fix the packet rate of best-effort traffic to be 10 packets per second, and gradually increase the real-time packet rate which is 10, 40, 45, 50, and 56 packets per second, respectively. As shown in Fig.4, all the best-effort packets can be received by the destination as long as the real-time packets generation rate is smaller than 40 packets/s. As the increasing of the real-time packet rate from 45 packets/s to 56 packets/s the best-effort packets have been dropped, however, the real-time packets could still be received entirely by the destination. It indicates that the cost of the delay guarantee for real-time traffic is a certain degree of throughput reduction of best-effort traffic, which is acceptable in the QoS support network.

![Fig.4. Received packets of best-effort traffic](image)

Finally, we evaluate the network lifetime for the proposed architecture. In this scenario, simulation duration is set to be 20 minutes, and all the nodes generate packets as the sources. Fig. 5 shows the first 10 nodes' death time when the sources generate packets at 5 packets/s and 50 packets/s, respectively. The results indicate that nodes can live longer in the proposed architecture than the conventional MANETs, no matter the traffic load is heavy or not.

If the network lifetime is defined as the period from the beginning of the simulation to the time when half of the nodes break down, our schemes can extend the network lifetime by 12.4% in Fig.5 (a) and up to 23.8% in Fig.5 (b), so it illustrates that our schemes can lead to a more obvious performance improvement when heavy traffic load is presented.
V. CONCLUSION

In this paper, we have presented an efficient architecture that uses distributed control scheme and status-aware routing protocol to support end-to-end QoS for real-time applications in MANETs. In the proposed architecture, the intra-flow interference model is introduced to estimate the available bandwidth for control scheme with the contention-based MAC layer, meanwhile, the status of remaining power capacity and traffic load at each node are exploited to select the best reliable route. An important benefit of our proposal is that both the control process and the routing protocol can be designed independently. Detailed simulations in different environments demonstrate that the proposed architecture could improve the end-to-end delay performance for real-time traffic and extend the network lifetime significantly. Therefore, the proposed architecture is efficient and feasible to provide QoS support in MANETs.

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