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Quality of service in mobile ad hoc networks

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With the expansion of real-time applications for mobile ad hoc networks the need for quality of service support has become essential. This paper deals with quality of service considerations in mobile ad hoc networks and provides a brief overview of the state of the art in this field. It contains the most up-to-date overview of QoS models, QoS routing, as well as resource reservation techniques and concludes with identifying some open issues in this challenging area.

1. Introduction

Mobile wireless ad hoc networks (MANETs) have become very popular nowadays due their simplicity by using and the ubiquity of wireless technology. As the growth of multimedia applications continues and the requirements for real traffic increase, there is a big challenge for researchers to find technologies and approaches satisfying these requirements. In the field of wireless ad hoc networking this is more challenging due to the dynamic network topology and bandwidth constraint. It has been done a lot of work in this area and there exist some papers providing Quality of Service (QoS) overview in mobile ad hoc networks (Lee, S. B. et al., 2000; Sivakumar, R. et al., 1999; Xiao, L. 2010).

This paper summarizes several of them and extends them with new approaches and protocols. It is organized as follows. Section 2 is a brief overview of QoS models and frameworks designed for MANETs. QoS signaling and various routing approaches are covered in section 3 and 4 respectively. Finally, section 5 contains conclusion and description of some open issues in this area.

2. QoS models and frameworks

QoS can be defined as the ability of the network to provide different services to various types of network traffic. It means that the goal of QoS is to achieve a more deterministic network behaviour so that data carried by the network can be better delivered and the resources can be better utilized. In wired networks there are four typical QoS metrics, namely, bandwidth, delay, delay variance (jitter) and packet loss. In MANETs service coverage area and power consumption can be added (Satyabrata, Ch., Amitabh, M., 2001).

In wired networks there are two QoS models widely used: IntServ (Integrated

Services) providing hard QoS but with low scalability, and DiffServ (Differentiated Services) used in the Internet. Unfortunately, both are not suitable for MANETs due to their specific characteristics. When QoS model for MANETs was designed, these specific features of mobile ad hoc networks had to have been considered. Especially, features like dynamic network topology, bandwidth constraint and limited power of nodes which make MANETs really specific. And due to them it is not possible to use conventional QoS models from wired networks. The design also needed to take under consideration the fact that a lot of MANETs are connected to the Internet. This section describes shortly three QoS models designed for mobile ad hoc networks.

2.1 Flexible QoS Model for MANETs

From essential requirements stated above Flexible QoS Model for MANETs (FQMM) was proposed. It combines some features of IntServ and Diffserv models. It is a hybrid scheme of per-flow provisioning as in IntServ and per-class provisioning as in DiffServ (Xiao, L., 2010).

FQMM operates at the IP layer with the cooperation with Medium-Access layer. It is divided into data forwarding and control plane. The main purpose of data forwarding plane is to classify incoming packets going through traffic conditioner and packet scheduler. The control plane handles preparation for data forwarding operation with specific protocols and algorithms cooperation. This model defines three categories of nodes: ingress, interior and egress node. This kind of nodes differentiation is borrowed from DiffServ model from wired networks. Ingress node is a source node sending data to destination. Interior nodes are nodes forwarding data to other nodes according to some routing decisions.

Lastly, the destination node is called egress node. Interior nodes forward data packets by certain PHB (Per Hop Behaviour) according to the Diffserv field in the packet header. We can look at MANET as one DiffServ domain bounded with the ingress and egress node (Chen, Y. et al., 2002). It is important to note that due to the mobility of nodes in MANETs, the nodes can have different roles as they move. FQMM can provide per flow QoS for high-priority flows. The question is how many high-priority flow sessions are possible in MANETs. Another open issue is the scheduling performed by intermediate nodes. The evaluation of FQMM performance and some experiments with this model can be found in (Lee, S. B. et al., 2000).

2.2 Integrated Mobile Ad hoc QoS framework

The Integrated Mobile Ad hoc QoS framework (iMAQ) is a QoS framework for MANETs. We cannot call it QoS model because it is not so complex and does not provide the whole architecture for QoS support in MANETs. It is a cross-layer approach involving network layer and so called middleware service layer.

As nodes are mobile, the network can become partitioned which leads to missing data. Predictive location-based QoS routing protocol, with middleware layer cooperation, predict network partitioning. The main role of middleware layer is to replicate data among different network groups in order to provide better data accessibility before partitioning occurs. More details about this framework can be found in (Nirmal, M. et al., 2004).

2.3 SWAN

SWAN is a distributed network model that assumes best effort medium-access control and feedback-based control mechanisms. It is a stateless approach using rate control for UDP and TCP best-effort traffic. It uses ECN (Explicit Congestion Notification) fields to regulate real-time traffic in order to react dynamically to topology changes. The fact that SWAN is a stateless model and thus it does not require maintaining information at network nodes makes it scalable and robust QoS model for MANETs. The details and evaluation study of SWAN model is described in (Basagni, S. et al., 2004; Zhang, N., Anpalagan, A., 2009).

3. QoS signaling

Signaling protocol is an important part of QoS support in networks generally. QoS signaling is used to manage the available resources in the network. Management of resources means reservation, setting up and tearing down. Signaling protocols can be divided into two groups. The first one called in-bound signaling is based on the transmission of control information carried in data packets, which means that control and data information is carried along the same path. The second group of signaling protocols, called out-of-band signaling, uses different approach with control information carried separately in control packets sometimes even along different paths than data packets.

Typical example of out-of-band signaling is RSVP protocol (Resource reSerVation Protocol) used in wired network. It became a standard and is widely used in the Internet environment. Due to its large overhead and missing capability of the fast response of dynamic topology changes, it is not used in MANETs. In general, in wireless networks out-of-band signaling is not very suitable because it consumes network bandwidth. Thus, it is a better idea to use in-band signaling which consumes less bandwidth and if control overhead is simple the information can be carried in each packet.

3.1 INSIGNIA

The first signaling framework as well as signaling protocol for mobile ad hoc networks, called INSIGNIA, is an example of in-band signaling. All control information is carried in the options part of IP packets. The basic term in this framework is flow and for each active flow in the network there is a soft state stored in all related hosts. The soft state is periodically refreshed every time when packets from the particular flow arrive at the hosts or are forwarded by the host to its destination. INSIGNIA, with admission control cooperation, reserves network resources, mainly available bandwidth, to the particular flow if the resource requirement coming from the source node can be satisfied. In order to keep INSIGNIA very simple and to not conserve much bandwidth, there are no error messages and thus no negative notification among network nodes. For example, if the resource requirement request cannot be satisfied, no error message is sent to source node.

Due to dynamic topology of MANETs, INSIGINA needs to respond fast to the topology changes. It is done by periodical informing the source node with the status of the data flow. The destination node gathers statistical information such as throughput, loss rate and many others and sends the report to the source node. With this kind of feedback, the source node can adapt the transmission of data packet belonging to the particular flow. Due to these attributes of INSIGNIA, it can provide assured adaptive QoS to real-time flows based on the source node requirements and resource availability in the MANETs (Nahrstedt, K., 2010).

3.2 INORA

Another QoS framework making use of INSIGNIA and TORA routing protocol is INORA. TORA provides multiple routes between given source and destination, and together with INSIGNIA signaling, provide QoS requirements for a flow. INORA also combines congestion control with routing (Enzai, N., 2008).

4. QoS routing

The main purpose of QoS routing is to find the path through the network, providing sufficient resources to meet QoS requirements. The common QoS requirements for real traffic are maximum delay threshold, minimum bandwidth threshold and constant jitter. The problem of finding the route with two or more QoS metrics in MANETs is NP-complete. Thus, it is very difficult to design and implement routing protocol that can be optimal in each situation. This section describes some of the most used routing protocols designed for QoS support in MANETs.

4.1 CEDAR

The Core Extraction Distributed Ad Hoc Routing (CEDAR) is a routing protocol that dynamically establishes the core of the network and then propagates the link states of stable and high-bandwidth links to the core nodes. The route selection and computation is on-demand and is performed by route nodes using only their local state information. This routing protocol consists of three components: core extraction, link state propagation and route computation. Core extraction means the election of some nodes which are then responsible for topology maintaining and path computation for their domain.

The election of core nodes is based on the approximation of mathematical principle called minimum dominating set of the network. The second component of CEDAR provides link state propagation from all network nodes to all core nodes. Only stable link states are propagated. The basic idea behind this approach is that the information about stable high-speed links should be known by core nodes, while the information about dynamic and low-speed links can remain within local area. Lastly, route computation part of CEDAR is self-explanatory, with the note that all computation is done by core nodes (Wu, K. Harms, J., 2001).

4.2 QoS AODV

Ad hoc On Demand Distance Vector routing protocol (AODV) was extended to support QoS. It includes object extension on Route Request (RREQ) and Route Reply (RREP) messages which specifies bandwidth or delay parameters during the phase of route discovery. A node becomes a hop on the route only if it can meet the requirements specified in the RREQ. If the route has been already established and the specified QoS requirement cannot be met no longer, the node originates an ICMP QOS_LOST message back to the source node (IIyas, M., 2003; Ramrekha, T. A., Politis, Ch., 2009; Xue, Q., Ganz, A., 2003).

4.3 Bandwidth routing

Bandwidth routing (BR) protocol operates only with bandwidth as QoS metric. Best path is the shortest path satisfying bandwidth requirements. The whole protocol consist of end-to-end path bandwidth calculation algorithm, bandwidth reservation and standby routing algorithm to re-establish the QoS flow in case of path breaks (Perkins, C. E., Royer, E.M., 1999).

4.4 On-Demand QoS Routing

On-Demand QoS Routing Protocol (OQR) is very similar to BR but network is time-slotted. Unlike BR it is not hybrid but it is a typical representative of reactive protocols thus route discovery is an important component. Another component is admission control that guarantees bandwidth for real-time applications.

4.5 On-Demand Link-State Multipath routing

The goal of On-Demand Link-State Multipath QoS Routing protocol (OLMQR) is to find multiple paths in network which collectively satisfy required QoS. The routing process consists of three phases. The first one is on-demand link-state discovery performed by flooding route requests (QRREQ). The second phase is so called unipath discovery and within it, there is maximum path bandwidth determination and time-slot reservation. Finally, the third phase is multipath discovery and reply. Along each unipath a reply (QRREP) is sent and multiple unipaths considered such that sum fulfils bandwidth requirements are determined (Perkins, C. E., Royer, E.M. (1999)). Against the big advantage of meeting bandwidth requirements over multiple paths, there is very high overhead of maintaining and repairing paths (Chunhung, R., 2001).

4.6 Asynchronous QoS Routing

Asynchronous QoS Routing does not require TDMA or CDMA-over-TDMA model in the network thus there is no need to time synchronization among nodes. It is based on DSR protocol (Dynamic Source Routing) and has three phases: bandwidth feasibility test, bandwidth allocation and reservation. The selection of paths, with needed bandwidth by route requests, is done in the first phase. Then, in the second phase, the destination selects the best path and sends a route reply with slots assignment information back to source.

The bandwidth reservation is done by intermediate nodes in the last phase. If reservation succeeds, route reply is forwarded to the next hop. If it fails, route reply is dropped and control packet is sent to inform the destination and to release already reserved resources across the path from particular node to the destination. The main disadvantage of this approach is its high setup and reconfiguration time (Nirmal, M. et al., 2004).

4.7 Predictive Location-Based Routing

This routing approach is based on the prediction of node locations. Instead of resource reservation along the path, there is an admission control performed at each node. This routing protocol uses two types of routing updates. The first one is regular update sent so that all nodes can have complete network topology. The second type of update indicates considerable changes in the topology and uses delay and location prediction schemes (Chen, Y. et al., 2002).

4.8 Ticket Based Routing

The basic idea of this distributed QoS routing protocol is that source node sends certain number of tickets as probes for finding QoS feasible path. The number of ticket corresponds to the number of paths that can be probed in parallel. During the route computation, there is imprecise state information maintained. The more tickets sent by the source node, the more precise the information is. As the evaluation tests show, this routing protocol has high performance even when the degree of imprecision is high (Nirmal, M. et al., 2004). The main reason for using this routing approach is that it provides multi-path routing and best path is selected as primary path, others are kept as backups. The trade-off is provided between control overhead and feasible path finding. The main issue is that global state is required to be maintained at each node, thus it is not very scalable solution (Xue, Q., Ganz, A., 2003).

4.9 QoS extension to Open Link State Protocol

Open Link State Protocol (OLSR) is a routing protocol for large and dense MANETs. It is based on proactive routing approach and uses hop-by-hop routing. Each node selects a set of neighbour nodes called multipoint relays (MPR). Only MPR nodes can forward control traffic. It can provide minimum delay and maximum bandwidth as QoS metrics. As the protocol belongs to the link-state routing protocols, the neighbour detection process is present here.

Each node detects its neighbours which it has a direct and bi-directional link with. The detection is done by HELLO messages containing the information about their neighbourhoods and link status. HELLO messages are received by all one hop neighbours but are not forwarded to further nodes. MPR set consists of subset of the one-hop neighbours which provides maximum bandwidth and minimum delay metrics to each two-hop neighbour. When a topology change or QoS condition in one or two-hop neighbours occurs, the MPR set is recalculated (Dharmaraju, D., Chowdhury, A., 2002).

4.10 Adaptive QoS routing

This routing approach, named CHAMELEON, provides adaptive routing solution with improved delay and jitter performance. It is called adaptive because it can adapt its routing behaviour according to the size of the network. For small MANETs the proactive mode of this protocol is used. If the size of the network enlarges, the protocol will operate in reactive mode. These modes are based on OLSR and AODV protocols respectively. A change mode packet is proposed in this protocol and it is sent if the network size exceeds the predefined threshold. The protocol implementation experience and performance evaluation results can be found in (Rishiwal, V. et al., 2009).

5. Conclusion and future work

In this paper QoS overview in MANETs has been briefly described. There have been proposed three basic QoS models and several QoS routing protocols as well as signaling approaches. The scope of this paper was not sufficient to provide the whole overview in this field, so only some of the most important topics were selected. For example, QoS support at medium-access layer or TCP protocol design for MANETs was not covered.

Although a lot of work has been done to provide QoS, there are still many open issues that need to be addressed by researches in the future. For instance, a lot of today's principles assume homogenous MANETs but many are heterogeneous in the nature. Other questions are related to security, robustness and scalability. Still open is also the question, if a node can refuse to be a router for other nodes in the network and then routing consequences of such behaviour. Lastly, multicast routing in MANETs is still a challenging open issue.

Our future work is aimed at QoS routing. We will compare and evaluate performance, scalability, robustness and correctness of QoS aware routing approaches and protocols. By means of network simulation we will point out the drawbacks and design some modifications or completely new QoS aware routing approach for mobile ad hoc networks.

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