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Intelligent QoS management for multimedia services support in wireless mobile ad hoc networks

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ABSTRACT

In this paper, we propose a new intelligent cross-layer QoS support for wireless mobile ad hoc networks. The solution, named FuzzyQoS, exploits fuzzy logic for improving traffic regulation and the control of congestion to support both real-time multimedia (audio/video) services and non-real-time traffic services. FuzzyQoS includes three contributions: (1) a fuzzy logic approach for best-effort traffic regulation (FuzzyQoS-1), (2) a new fuzzy Petri nets technique (FuzzyQoS-2) for modeling and analyzing the QoS decision making for traffic regulation control, and (3) a fuzzy logic approach for threshold buffer management (FuzzyQoS-3). In FuzzyQoS-1, the feedback delay information received from the network is used to perform a fuzzy regulation for best-effort traffic. Using fuzzy logic, FuzzyQoS-3 uses fuzzy thresholds to adapt to the dynamic conditions. The evaluation of FuzzyQoS performances was studied under different mobility, channel, and traffic conditions. The results of simulations confirm that a cross layer design using fuzzy logic at different levels can achieve low and stable end-to-end delay, and high throughput under different network conditions. These results will benefit delay- and jitter-sensitive real-time services.

1. Introduction

Wireless ad hoc networks are a new technology in the evolution of wireless communications. In this technology, wireless devices can communicate with each other in the absence of a fixed infrastructure. Ad hoc networks usually consist of a set of nodes that communicate over wireless links in a multihop manner without a need for a central control, which creates a high level of flexibility to users.

With the widespread use of wireless technology, the ability of mobile wireless ad hoc networks to support real-time services with Quality of Service (QoS) has become a challenging research subject. The notion of QoS satisfaction is defined as the guarantee by the network to satisfy some predetermined service constraints for users in terms of end-to-end delay, available bandwidth, etc. However, the QoS issue is yet a challenging task in ad hoc networks because there is no fixed infrastructure and the topology is frequently changing due to nodes mobility. Furthermore, links are constantly established and broken. The availability and quality of a link fluctuates due to channel fading and interference from other transmitting devices. Various approaches and protocols have been proposed to address QoS ad hoc networking problem [1–12]. Multiple efforts are also still under way within academic and industrial research projects.

SWAN [1], INSINGIA [2], and FQMM [3] are some noteworthy QoS models attempting to establish comprehensive QoS solutions for MANETs. SWAN proposes service differentiation in stateless wireless ad hoc networks using distributed control algorithms and a rate control system at each node. However, one of the drawbacks of SWAN is how to calculate the threshold rate limiting any excessive delay that might be experienced [4]. It also uses merely two levels of services: real-time and best-effort traffic. SWAN and INSIGNIA are intranet QoS models providing services that

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have to be mapped to either per-flow or per-class services, but SWAN remains the best example of stateless distributed QoS framework developed for wireless ad hoc networks. INSIGNIA is on the other hand, a QoS framework with per-flow granularity and reasonable treatment for mobility. The main goal of INSIGNIA is to provide adaptive QoS guarantees for real-time traffic. It employs an in-band signaling system that supports fast reservation, restoration, and adaptation algorithms. Three levels of services are implemented: best-effort, minimum, and maximum. The bandwidth is the only QoS parameter used in INSIGNIA. FQMM is another approach combining the advantages of per-class granularity of DiffServ with the per-flow granularity of IntServ. It tries to preserve the per-flow granularity for a small portion of traffic in MANETs, given that a large amount of the traffic belongs to per aggregate of flows, that is, per-class granularity. FQMM offers a good solution for small and medium-size ad hoc network, but it is not suitable for large networks.

Recently, some intelligent methods have been applied in the area of ad hoc networks, aiming to obtain more adaptive and flexible models over the existing models. In [13], the authors developed a SHROT model, which is a dynamic source routing protocol using a self healing and optimized routing techniques based on fuzzy logic concepts. The basic idea of this model is the modification of the entries of the neighbour table and the time-stamp of each entry based on fuzzy system. The model AntNet proposed in [14] is an adaptive algorithm based on mobile-agents. This algorithm is inspired by work on the ant colony metaphor. In AntNet, each node periodically launches network exploration agents called forward ants to every destination. At each node, the ants will choose their next hop using that nodes routing table. As the ants visit a node, they record their arrival time and the node identity in a stack [14]. In [15], the authors describe a policy-based management system for improving the flexibility of wireless mobile ad hoc network. This system provides the capability to express networking requirements in the form of policies at a high level and have them automatically applied in the network by intelligent agents [15]. The model proposed in [16] investigates the use of fuzzy logic theory for assisting the TCP error detection mechanism in ad hoc networks. An elementary fuzzy logic engine was presented as an intelligent technique for discriminating packet loss due to congestion from packet loss by wireless induced errors.

In [6], we have proposed an intelligent QoS model with service differentiation based on neural networks for mobile ad hoc networks named GQOS. GQOS is composed of a kernel plan which ensures basic functions of routing and QoS support control, and an intelligent learning plan which ensures the training of GQOS kernel operations by using a multilayered feedforward neural network (MFNN). The objective of using neural networks was the fast learning of the different operations performed by the kernel and the reduction of the processing time in the network. However, GQOS is not scalable in terms of end-to-end delay under higher network mobility and traffic load.

We have explored in [7] the usage of a fuzzy logic semi-stateless approach for service differentiation in wireless ad hoc networks. The proposed model named FuzzyMARS includes a set of mechanisms: admission control for real-time traffic, a fuzzy logic system for best-effort traffic regulation, and three schemes for real-time traffic regulation. FuzzyMARS architecture support real-time UDP traffic as well as TCP traffic. The resulted simulations have shown the benefits of using a fuzzy logic semi-stateless model; the average delay obtained is quite stable and low under different network conditions. Nevertheless, in FuzzyMARS we considered neither buffer management nor QoS decision making for traffic regulation.

In this paper, we explore an integrated new intelligent cross-layer QoS solution based on fuzzy logic for wireless mobile ad hoc networks. This choice is justified by the fact that fuzzy logic is well adapted to systems characterized by imprecise states, as in the case of ad hoc networks. The proposed approach, FuzzyQoS, aims to improve the control of traffic regulation rate and congestion control of multimedia applications. FuzzyQoS integrates three mechanisms at different layers: a fuzzy logic approach for best-effort traffic regulation (FuzzyQoS-1), QoS decision making for traffic regulation (FuzzyQoS-2), and a fuzzy logic approach for threshold buffer management (FuzzyQoS-3). The delay feedback information received from the network is the key parameter used in FuzzyQoS-1 and FuzzyQoS-2, to ensure that best-effort traffic coexists well with real-time traffic in the multimedia applications. The feedback measurement represents the packet delay measured by the IEEE 802.11 MAC which is integrated as a part of the FuzzyQoS architecture. The objective of the FuzzyQoS-1 is to dynamically adjust the transmission of traffic according to the network conditions.

FuzzyQoS-2 is a fuzzy Petri nets technique for modeling and analyzing the QoS decision making for traffic regulation in wireless ad hoc networks. FuzzyQoS-2 exploits fuzzy concepts to model the QoS decision making by the source nodes. The fuzzy Petri nets tool is used for its efficiency and flexibility over other modeling tools (such as Petri nets) with the objective of better modeling and representing the process of traffic regulation.

Finally, FuzzyQoS-3 uses fuzzy thresholds to adapt to the dynamic conditions of the network. The notion of threshold is practical for discarding data packets and adapting the traffic service depending on the occupancy of buffers. The threshold function has a significant influence on the performance of networks in terms of both packets average delay and throughput. Therefore, the selection of a particular threshold may be decisive to the control of congestion. This selection in the proposed FuzzyQoS model is based on fuzzy logic.

We studied FuzzyQoS performances under different network conditions in terms of mobility and scalability. The results of simulations, shown in Section 3, confirm that FuzzyQoS promises to be an efficient QoS solution in terms of the average delay and throughput to support both real-time and non-real-time multimedia services.

The objective of the integration of these three mechanisms is to find a good balance between network performances (by improving the end-to-end delay parameter using FuzzyQoS-1 and FuzzyQoS-2 mechanisms) and reliability (by improving the throughout parameter using FuzzyQoS-3).