Journal of Mobile Communication 1 (4): 114-120, 2007
ISSN: 1990-794X

A Cross Layer Based QoS Model for Wireless and Mobile Ad Hoc Networks

P. Venkata Krishna and S.N. Iyengar
School of Computing Sciences, VIT University, Vellore, Tamilnadu-632014, India

Abstract: The cross-layer design approach is an efficient procedure used to solve several open issues of mobile and wireless networks. Cross-layer design is used to share the information between layers and promotes adaptability at various layers based on information exchanged. However, such a design process needs to be carefully coordinated to avoid unintentional and undesirable consequences. The basic idea of cross layer approach is to overcome performance problems by allowing protocols belonging to different layers to cooperate and share network status information to maintain the Quality of Service. This study presents a QoS model based on cross layer concepts for Mobile and wireless environments.

Key words: Cross layer, services, mapping, QoS models, wireless

INTRODUCTION

The networks in which the nodes communicate over a wireless channel are referred as wireless Ad-hoc networks. A Mobile Ad-hoc Network (MANET) is a set of wireless mobile nodes dynamically forming a temporary network. The goal of this architecture is to provide communication facilities between end-users without any centralized infrastructure. In such a network, each mobile node operates not only as a host, but also as a router. This type of networking is a challenging task due to the lack of resources residing in the network as well as frequent changes in network topology. Ad-hoc communications involves the interaction of all layers in OSI protocol and a good cross layer model would definitely be useful in sharing information between different layers and improve QoS (Chen *et al*., 2004). In the protocol stack, the network layer converge heterogeneous networks in an all IP of the next generations; the application layer supports three high-level mobility types (Qi Wang and Abu-Ragheff, 2003). Traffic on wireless networks is expected to be real time traffic like voice, multimedia teleconferencing and non-real time traffic like data, web browsing and file transfers. All of these require widely varying QoS guarantees for different types of offered load (Shakkottai *et al*., 2003).

Mobile ad hoc networking is a challenging task due to the lack of resources resides in the network as well as the frequent changes in network topology. Although, lots of researches have been done on supporting QoS in the Internet and other networks, they are not suitable for mobile and wireless networks and still QoS support for such networks remains an open problem. The dynamic nature of Ad hoc networks makes system design a challenging task. Mobile ad hoc networks suffer from severe performance problems due to the shared, interference-prone and unreliable medium. Routes can be unstable due to mobility and energy can be a limiting factor for typical devices such as mobile phones and sensor nodes. In such environments cross-layer architectures are a promising new approach, as they can adapt protocol behavior to changing networking conditions (Rolf Winter *et al*., 2006). Normally, the network can be organized as a series of different layers. The purpose of each layer is to offer certain services to the next higher layer and this provides a level of transparency by shielding the higher layers from the details of how the lower layer services are being implemented. This approach helps to reduce complexity by splitting the network into smaller modules with different functionalities such that each function can be dealt with more manageably and indirectly it also facilitates the development of new protocol standards at various layers of the protocol stack. Such a structured approach to network design helps to provide easy standardization, inter-layer interoperability and peer-to-peer relationships among different networks and equipment. With wireless networks, the dynamic behavior of the wireless channel poses many difficult challenges.

The conventional protocol stack is inflexible as various protocol layers communicate in a strict manner. In such a case, the layers are designed to operate under the worst conditions as opposed to adapting to changing conditions and this often leads to inefficient utilization of available frequency spectrum and energy resources. A paradigm shift is also beginning to take place as wireless

Corresponding Author: P. Venkata Krishna, School of Computing Sciences, VIT University, Vellore, Tamilnadu-632014, India

communications evolves from a circuit-switched infrastructure to a packet-based infrastructure and a certain level of QoS may be required to support future applications in wireless networks. The question now is how to provide and maintain a certain level of QoS in such highly dynamic environment? One possible alternative is by cross-layer design and adaptation.

The concept behind cross-layering is rather intuitive. Instead of treating a layer as a completely independent functional entity, information can be shared among layers. The ability to share information across layers is the central aspect of cross layer design. So, instead of a mere replacement, cross layering can be seen as an enhancement of the layered approach. The ultimate goal is to preserve the key characteristics of a layered architecture and in addition to allow for performance improvements and adaptability (Rolf Winter *et al*., 2006). The gains that can be achieved by means of a cross-layer approach, where physical layer information is passed to the higher layers are TCP traffic over wireless links, supporting data services in a multi-user wireless network (Shakkottai *et al*., 2003). Cross layer seems to be a promising new approach in that they open up a whole new set of possibilities in terms of performance and adaptability. On the other hand, they add a degree of complexity and could create adaptability loops. In dynamic networked environments such as ad hoc networks, there are a lot of intrinsic performance bottle necks and an obvious need to adapt to rapidly changing conditions. The mobility of nodes is also a significant system dynamic. It can affect the stability of routes, which in turn could cause broadcast storms to re-establish routes consuming large amount of scarce resources such as bandwidth and energy. In such environments, cross-layer approaches are promising since performance and scalability can significantly be improved (Rolf Winter *et al*., 2006).

In wireless networks, there is a tight interdependence between layers. Cross-layer design can help to exploit the interactions between layers and promotes adaptability at various layers based on information exchanged. However, such a design process needs to be carefully coordinated to avoid unintentional and undesirable consequences. It is often hard to characterize the interactions between protocols at different layers and the joint optimization across layers may lead to complex algorithms, which would later result in problems with implementation, debugging, upgrading and standardization. As the performance of adjacent layers are inter-related, it is equally important to fully understand this interdependency relationship and carefully analyze their responses as optimization processes at different layers could go in opposite directions.

By exploiting the lower layer information through a cross-layer concept, performance benefits may be obtained. At the physical layer, channel estimation is performed to obtain the instantaneous Signal-to-Noise Ratio (SNR) of a link and this information is used to select the data rate, which affects the transmission delay. At the network layer, the routing protocol then makes a decision based on the delay associated with each link, which it will then evenly spread the network load distributions across the available links and thus optimizing the performance of the lower layers.

MANET becomes a challenging task due to the frequent changes in network topology and the lack of the network resources both in the wireless medium and in the mobile nodes. Because of this, routing in such networks experiences link failure more often. Hence, a routing protocol that supports QoS for ad hoc networks requires considering the reasons for link failure to improve its performance. Link failures are mainly due to node mobility and lack of the network resources. Furthermore, the routing protocols must be *adaptive* to cope with the time-varying low-capacity resources. For instance, it is possible that a route that was earlier found to meet certain QoS requirements no longer does so due to the dynamic nature of the topology. In such a case, it is important that the network intelligently adapts the session to its new and changed conditions.

Related works: Yuen *et al*. (2002) proposes a novel cross-layer design concept that could improve the network throughput significantly for mobile ad hoc networks. Most routing protocols are designed with less emphasis on the issues at the lower layers. These include the variable link capacity at the physical layer and the fluctuating contention level at the mac layer. To overcome this gap, Yuen *et al*. (2002) introduces a cross layer design concept, by exploiting the lower-layer channel information, such as the variable link capacity through spectrally efficient rate adaptation and contention level estimation at the mac layer. Stavros Toumpis and Goldsmith (2003) focuses on power control, the queuing discipline the choice of routing and media access protocols and their interactions. Qi Wang *et al*. (2003). Multi-layer mobility management architecture which uses cross-layer interactions is aimed at an advanced mobility support for personal mobility, session mobility, service mobility as well as the traditional terminal mobility in a hybrid heterogeneous system. Shakkottai *et al*. (2003) addresses the issue of cross-layer networking, where the physical layer and mac layer knowledge of the wireless medium is shared with the higher layers. Imanol Martnez proposes a new architecture based on the integration between the cross-layer concept and priority queuing. In this architecture, one node is aware of the state of other components of the network.

Xiao Qin Chen proposes a novel cross-layer design for mobile to mobile adhoc networks. This shceme makes use of the statistical characteristics of the fast fading channel and cross-layer concept to combat rayleigh fast fading and improve radio channel utilization. A Linear Minimum Mean Square Error (LMMSE) estimator employs past channel auto correlation data to estimate the future fading status at the physical layer.

Ulas *et al*. (2004) proposes a frame work for cross-layer design towards energy efficient communication, characterized by a synergy between the physical and the medium access control layers with a view towards sinclusion of higher layers as well.

Taesang Yoo *et al*. (2004) Focuses on the joint optimization of capacity and flow assignment for live video streaming minimizes network congestion. The optimal capacity assignment lies on the edge of the capacity region and is determined by time sharing among different transmission schemes. Network congestion, a quantity reflecting the amount of delay experienced by the video packets, is chosen to be the cost function.

Lijun Chen proposes a Problem of congestion control and resource allocation over a multi hop wireless ad hoc network. Presented a model for the joint design of congestion control, routing and scheduling for adhoc wireless networks by extending the frame work on network utility maximization and applying dual-based decompositions. Congestion control, routing and scheduling jointly solve the network utility maximization problem.

Rolf Winter and Jochen (2006) proposes CrossTalk, a cross-layer architecture that aims at achieving global objectives with local behavior. It further compares CrossTalk with other cross-layer architectures proposed. Finally, it analyzes the quality of the information provided by the architecture and presents a reference application to demonstrate the effectiveness of the general approach Lamia and Bonnet (2006) proposes Cross-Layer Forwarding Strategy (CLFS) which is based on cooperation between MAC (EDCA) and routing layers (AODV).

QOS MODELS

The presence of mobility implies that links failures often in an nondeterministic manner. This dynamic nature makes routing and consequently QoS support in these networks fundamentally different from fixed networks (Wu and Harms, 2001; Chen and Nohrstedt, 1999; Perkins and Hughes, 2002; Chalmers and Sloman, 1999). The Quality of Service of the network in terms of available resources resides in the wireless medium and in the mobile nodes varies with lot of issues such as delay; throughput etc and the present QoS models are insufficient for such networks (Xiao and Ni, 1999). It has to be mentioned that a QoS Model does not define specific protocols or implementations. Instead, it defines the methodology and architecture by which certain type of services can be provided in the network with quality.

Integrated services: Integrated Services (IntServ) well known as per flow service and popular in Internet services allows sources to communicate their QoS requirements to routers and destinations on the data path by means of a signaling protocol such as RSVP (Lixia Zhang *et al.*, 1993; Braden *et al.*, 1997). Hence, IntServ provides per-flow end-to-end QoS guarantees. IntServ defines two service classes: *Guaranteed service* (Shenker *et al.*, 1997) and *controlled load* (Wroclawski, 1997), in addition to the *best effort* service. In guaranteed service, the network provides some sort of service guarantee to individual users or group of users. In best effort service, the network makes no promises. This service is typically used by elastic traffic (Shakkottai *et al.*, 2003). The guaranteed service class guarantees to provide a maximum end-to-end delay and is intended for applications with strict delay requirements. Controlled load, on the other hand, guarantees to provide a level of service equivalent to best effort service in a lightly loaded network, regardless of network load. This service is designed for adaptive real-time applications.

Differentiated services: The differentiated service architecture tries to gather or map the traffic types present in the network in different service classes. The application of this idea in ad hoc networks seems to be valid. The diffserv architecture implies hop-by-hop treatment of each data packet, that way the management procedure is distributed to all the nodes in the networks and minimizes the use of signaling and control packets. DiffServ architecture avoids the problem of scalability by defining a small number of Per-Hop Behaviors (PHBs) at the network edge routers and associating a different DiffServ Code Point (DSCP) in the IP header of packets belonging to each class of PHBs. Core routers use DSCP to differentiate between different QoS classes on per-hop basis. In DiffServ, we can identify three different classes *expedited forwarding*, *assured forwarding* and *best effort*. Expedited forwarding provides a low delay, low loss rate and an assured bandwidth. Assured forwarding provides guaranteed/expected throughput for applications and best effort which provides no guarantee.

DiffServ and IntServ require accurate link state (e.g. available bandwidth, packet loss rate, delay and etc.) and topology information. The time-varying low-capacity resources of the network make maintaining accurate routing information very difficult.

However, the study proposes a quality of service model for mobile and wireless environments based on the existing QoS models using cross layer concepts. The proposed QoS model will provide support for real-time flows in the system with admission control, marking of flows, signaling and bandwidth management.

CROSS LAYER BASED QOS MODEL

Unlike fixed networks such as the Internet, quality of service support in mobile ad hoc networks depends not only on the *available resources* in the network but also on the *mobility rate* of such resources. Furthermore, mobile ad hoc networks potentially have less resource than fixed networks. Therefore, more criterions are required in order to capture the quality of the links between nodes, best paths and alternate paths, channel access methods, congestion and flow mechanisms. The proposed QoS model uses Back and Forth Information Flow where 2 new interfaces is created between 2 layers for flow of information in both ways, this iterative loop between 2 layers occurs if and only if two layers are performing different tasks, wants to collaborate with each other at run time. The model is based on the division of the network features in four main groups Application Layer Metrics (ALM), Transport Layer Metrics (TLM), Network Layer Metrics (NLM) and MAC Layer Metrics (MLM) (Fig. 1). The ALM defines the classification of the traffic type in the different service classes that are going to be used by the network such as Type I, II and III services. The type I service is the one with the highest priority followed by type II service and Type III. The TLM defines congestion notification based on ECN. This metric offers information of buffers, information about congestion by using Random Early Detection (RED). The NLM provides information about best paths and alternate paths, bandwidth and priority re-allocation. Finally, the MLM are related with the control signaling, channel access and delay information.

Cross Layer Interactions And Service Mapping (CLIASM): The proposed Cross Layer Interactions And Service Mapping (CLIASM) can be implemented by using a shared database. The concept is to develop a shared data base which stores information about various layers protocol information such as MLM, NLM, TLM and ALM and QoS issues. These metrics will be useful to select the required QoS for an application and these metrics are accessed by various layers through shared database before making communication as shown in Fig. 2.

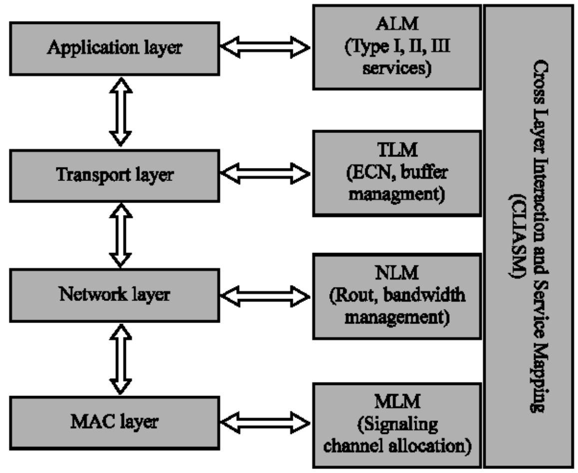

Fig. 1: Cross layer based QoS model

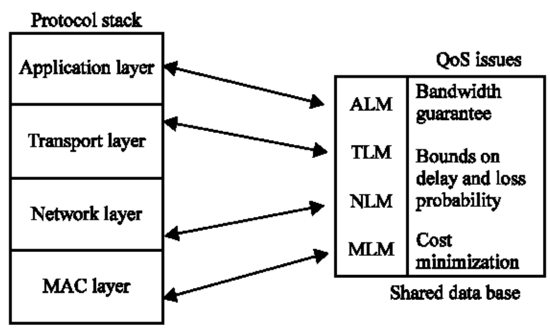

Fig. 2: CLIASM through a shared database

Table 1: Service categories and types

Type	Service category	Mobility
Type I : High priority	Real time/non real time	Fixed/mobile
Type II: Medium priority	Real time/non real time	Fixed/mobile
Type III: Low priority	Real time/non real time	Fixed/mobile

Application Layer Metric structure (ALM structure): ALM structure stores the information about various services of different applications. Service for various applications depends on the type of service and level of QoS required. The ALM structure stored in shared data base provides QoS information by accessing other metric information. The ALM message structure is defined as follows

ALM (Type, Service Category, mobility)

Transport Layer Metric structure (TLM structure): TLM structure stores the information about transport issues such as congestion status of the network. The TLM message structure is defined as follows

TLM (ECN (CE, CWR), buffer size) (Table 2)

Table 2: ECN marking mechanism

CWR	ECE	Congestion	Buffer management
0	0	No congestion or non ECN-capable	Increase window additively
0	1	Incipient congestion	Decrease window multiplicatively by 20%
1	0	Moderate congestion	Decrease window multiplicatively by 40%
1	1	Severe congestion	Decrease window multiplicatively by 50%

Table 3: Simulation parameters

Number of nodes	20
Number APs	4
Routing protocol	AODV
Minimal packet size	32
Maximal packet size	512
End-to end delay	10 msec
MAC	802.11 DCF
Congestion	ECN

Network Layer Metric structure (NLM structure): NLM structure stores the information about Network issues such as node information, path selection metrics like delay and bandwidth (Table 3). The NLM message structure is defined as follows

NLM (Node Identification, Route Table (path, delay, capacity))

MAC Layer Metric structure (MLM structure): MLM structure stores the information about media access issues such as SNR, packet collisions and channel allocation status of the network. The MLM message structure is defined as follows

MLM (SNR, Channel allocation (G1, G2, G3))

The above 4 message structures are useful to analyze the network condition so that the performance of the wireless network improves significantly by sharing metric information through a common database optimally.

PERFORMANCE EVALUTATION

The proposed cross layer architecture will improve the performance of a wireless network. Here we present performance of routing protocols which are developed based on the proposed CLIASM. Routing protocols are developed to work around typical limitations of the networks, which include high power consumption, low bandwidth and high error rates. In the case of source initiated routing protocols, as the name suggests routes are established whenever a need to communicate with a particular node arises. In contrast to table-driven routing protocols, all routes are not updated at every node instead the routes are discovered whenever required. When a source wants to send data to a destination node, it invokes the route discovery mechanism to find the route to the destination node. The route remains valid until the destination is reachable or the route is no longer needed. One of the best Source initiated on-demand routing protocols is Ad Hoc On-Demand Distance Vector Routing. The traditional AODV is implemented based on proposed cross layer architecture (CLIASM) and the modifications are as follows:

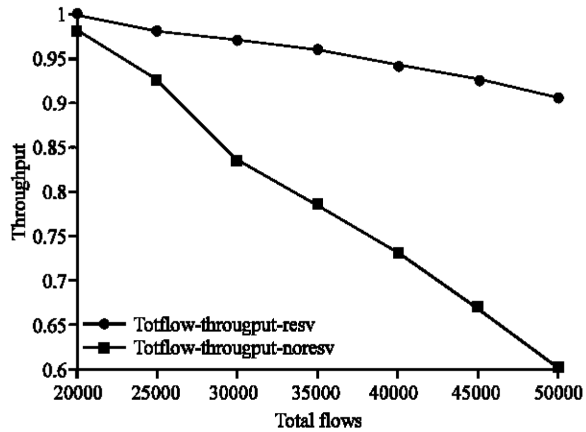

Fig. 3: Average Normalized throughput Vs total number of flows

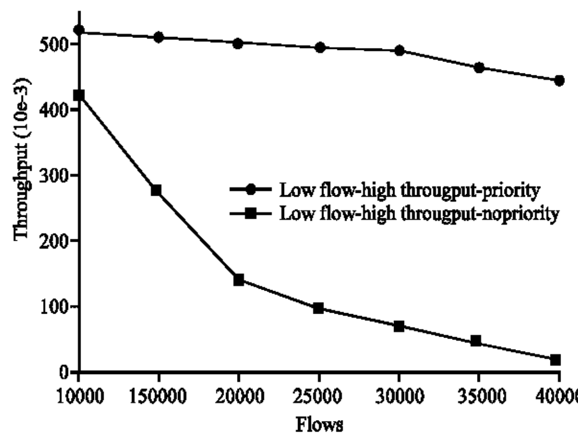

Fig. 4: Average Normalized throughput for low priority flows

Step 1: Mobility trace is obtained from Application layer metric.

Step 2: Route discovery based on AODV method using Transport and MAC layer metrics

Now, the modified AODV routing is useful to select the best path between source and destination and also it ensures minimum bandwidth for its routes. The performance of AODV routing protocol is improved because of cross layer interactions as shown in Fig. 3. It

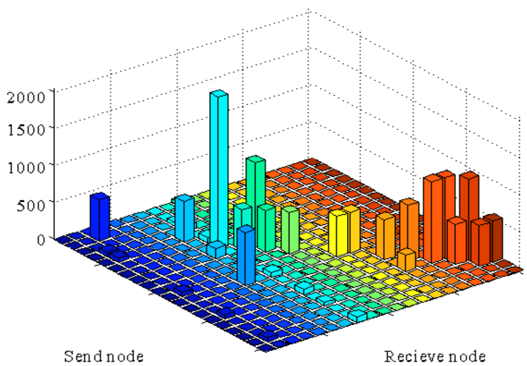

Fig. 5: Number of bytes received at various nodes

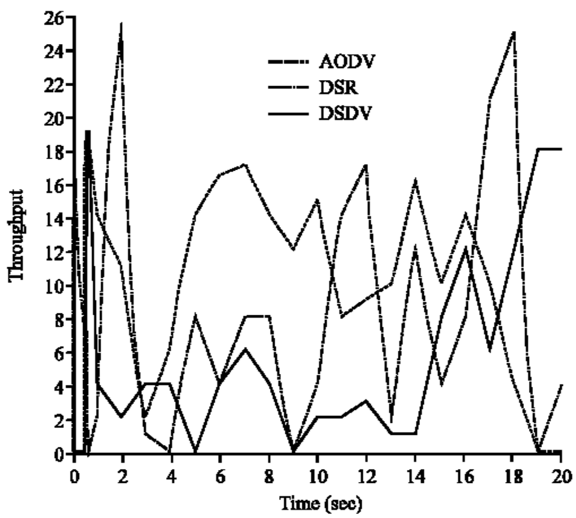

Fig. 6: Comparision of three routing protocols (AODV, DSR and DSDV)

is observed that the average normalized throughput of the system is better when comparing with existing protocols.

The throughput of low priority flows is also increased greatly based on the cross layer interactions as shown in Fig. 4. The total of number of bytes received by various nodes set up in the wireless network is shown in Fig. 5. Figure 6 shows the comparison of three routing protocols namely AODV, DSR and DSDV. It is observed that the performance of AODV is better than other two protocols.

CONCLUSION

The study presents a QoS based cross-layer architecture based on shared database model for wireless networks. The proposed model allows to share various information across the layers through a common database. The database stores information about various QoS related information such as ALMs, TLMs, NLMs and MLMs. The proposed model is evaluated for routing protocols like AODV, DSR and DSDV. It is observed that the performance of these protocols are improved using CLIASM.

REFERENCES

Braden, R., L. Zhang, S. Berson, S. Herzog and S. Jamin, 1997. Resource Reservation Protocol (RSVP)-version 1 functional specification. IETF RFC 2205.

Chalmers, D. and M. Sloman, 1999. A survey of QoS in mobile computing environments. IEEE Communications Surveys.

Chen, S. and K. Nahrstedt, 1999. Distributed quality-of-service routing in ad hoc networks. IEEE J. Selected Areas in Commun., Vol. 17.

Lamia, R. and C. Bonnet, 2006. A cross-layer feature for an efficient forwarding strategy in wireless ad hoc networks. 20th Int. Conf. Adv. Inform. Networking and Applications, AINA., 1: 741-746.

Lixia, Z., S. Deering and D. Estrin, 1993. RSVP: A new resource reservation protocol. IEEE Network.

Perkins, D.D. and H.D. Hughes, 2002. A survey on quality-of-service support for mobile ad hoc networks. Wireless Communications and Mobile Computing.

Qi Wang and M.A. Abu-Rgheff, 2003. A multi-layer mobility management architecture using cross-layer signalling interactions. IEEE Conference on Personal Mobile Communications, 2003. 5th Eur. Conf. Publ., pp: 237-241.

Rolf, W., J.H. Schiller and F.U. Berlin, 2006. CrossTalk: Cross-layer decision support based on global knowledge. IEEE. Commun. Mag., 44: 93-99.

Shakkottai, S., T.S. Rappaport and P.C. Karlsson, 2003. Cross-layer design for wireless networks. IEEE. Commun. Mag., 41: 74-80.

Shenker, S., C. Partridge and R. Guerin, 1997. Specification of guaranteed quality of service. RFC 2212.

Stavros, T. and A.J. Goldsmith, 2003. Performance, optimization and cross-layer design of media access protocols for wireless ad hoc networks. IEEE. Int. Commun., 3: 2234-2240.

Taesang, Y., E. Setton, X. Zhu, A. Goldsmith and B. Girod, 2004. Cross-layer design for video streaming over wireless ad hoc networks. IEEE 6th Workshop on Multimedia Signal Processing, 29: 99-102.

Ulas, C.K., I. Koutsopoulos and L. Tassiulas, 2004. A framework for cross-layer design of energy-efficient communication with QoS provisioning in multi-hop wireless networks. Twenty-third Ann. Joint Conf. IEEE. Comput. Commun. Societies, INFOCOM., 2: 1446-1456.

Wing Ho Yuen, H. Lee and T. Andersen, 2002. A simple and effective cross layer networking system for mobile ad hoc networks. The 13th IEEE. International Symposium on Personal, Indoor and Mobile Radio Commun., 4: 1952-1956.

Wroclawski, J., 1997. Specification of the controlled-load network element service, RFC 2211.

Wu K. and J. Harms, 2001. QoS support in mobile ad hoc networks.

Xiao, X. and L.M. Ni, 1999. Internet QoS: A big picture. IEEE. Network, pp: 8-18.