A flexible QoS-aware routing protocol for infrastructure-less B3G networks

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ABSTRACT

Current mobile devices support multiple network technologies and network composition via such devices can enable service provisioning across heterogeneous networks. One of the key challenges for realizing this view is inter-domain routing. Indeed, given the diversity of involved network technologies and infrastructures, a flexible routing protocol that takes into account their quality properties and dynamics is an important requirement. In this paper, we present a flexible quality-aware routing protocol for infrastructure-less B3G environments that enables discovery of routes with optimal bandwidth, delay or cost according to the preference of each client. The protocol is based on the Optimized Link-State Routing (OLSR) protocol and is designed to enable computation of quality-aware routes in multi-network environments. We detail the protocol, discuss its deployment and provide experimental results.

Categories and Subject Descriptors

C.2.2 [**Computer-Communication Networks**]: Network Protocols—*routing protocols*

Keywords

B3G network, Quality of Service, routing protocol, OLSR

1. INTRODUCTION

Modern mobile devices combine different user input interfaces (e.g. keyboard, voice, touch screens), functionalities (e.g. telephone, camera, media player) and connectivity technologies (e.g. Wi-Fi, UMTS, Bluetooth), providing users with a powerful mobile computing platform and enabling the convergence of multiple IP-based networks, both infra-structured or ad hoc. Such environments are referred to as *beyond third generation* systems, or simply B3G [11]. We consider an infrastructure-less B3G environment that integrates loosely-coupled IP-based networks under different administrative domains but where global routing is not available. *Multi-homed devices*, also called *bridges*, route traffic across various networks, voluntarily dedicating a certain amount of resources (e.g., processor time) to handle packets from other users. An incentive mechanism can be used to encourage users to share resources; we refer the interested reader to [10].

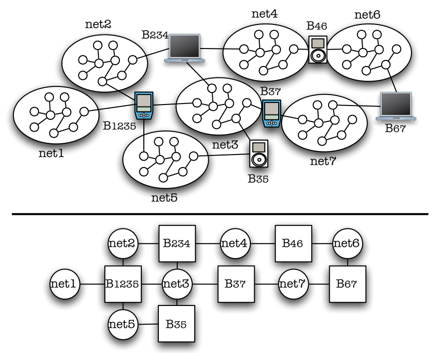


Figure 1: A B3G topology and its bipartite graph

To model this topology, the view of networks as graphs where devices are represented by nodes while connections are modeled as edges is no longer appropriate. Since different bridges can be connected to the same network, the topology of a multi-network routing protocol is better represented by a bipartite graph (as depicted in Fig. 1), where nodes are divided in two groups and every edge connects nodes in different groups. Even if bridges are connected to each other, the characteristics of the network connecting them must be taken into account and the same representation applies.

This deployment topology has two advantages. First, by restricting multi-network routing to bridges and thus reducing the number of nodes involved into inter-domain routing, route computation becomes faster. Second, this topology allows each network to be autonomously organized and locally use the most appropriated routing protocol, since imposing a single routing protocol to all dynamically composed networks would be impractical.

Quality of Service (QoS) provisioning in such environments is an important challenge [12]. To address this issue, we propose a proactive QoS-aware routing protocol inspired by the Optimized Link-State Routing (OLSR) [8]. Our protocol is run by bridges in the B3G environment and enables users and applications to discover routes optimizing their bandwidth, delay or cost according to the specific needs of each client at a given moment of time, without additional protocol reconfiguration.

The paper is organized as follows. In Sect. 2, we provide a brief overview of OLSR, explain how QoS characteristics are defined in our scenario, introduce a novel OLSR-based QoS-aware routing protocol for multi-network environments and prove some of its properties. In Sect. 3, we discuss and experimentally evaluate our protocol. In Sect. 4, we review related work. Finally, in Sect. 5, we present our final remarks and outline future work.

2. A FLEXIBLE INTER-DOMAIN QOS-AWARE ROUTING PROTOCOL

Ad hoc routing protocols are designed to minimize control traffic. There are two basic approaches to ad hoc routing: *proactive protocols* (such as [1]) keep routing information up-to-date even when routes are not used but present low latency to find routes, while in *reactive protocols* (such as [15]) nodes only exchange messages when a route is required, but the latency to find a route is higher. In [4] we discuss the privacy benefits of proactive protocols over reactive protocols and conclude that route requests in reactive protocols can disclose communication details and impact the user privacy. For that reason, and since the topology of infrastructure-less B3G networks reduces the overhead of proactively updating routes, in this work we adopt the proactive strategy for routing and introduce a quality-aware extension to OLSR.

2.1 OLSR Overview

OLSR is an enhancement of the traditional Link-State Routing (LSR) used in wired networks. LSR is not efficient in terms of control traffic overhead because each node advertises all links to all nodes, resulting in unnecessary retransmissions of control messages and large size of routing tables. OLSR uses Multi-Point Relays (MPRs) to reduce this overhead. Each node independently selects its MPR set as the smallest set of its one-hop neighbors such that all its two-hop neighbors are covered, and only MPRs retransmit control messages, reducing control traffic while still keeping the shortest route between any two nodes.

OLSR basically uses two types of messages: *HELLO* and *Topology Control (TC)*[1]. Each node sends HELLO messages periodically to advertise its presence, its links with other neighbors and its MPR set. After all nodes have exchanged HELLO messages, each node knows its two-hop neighborhood and for which nodes it has to retransmit TC messages (those who selected it as MPR). TC messages are used to propagate topology information, and contain only the nodes that selected the TC message source node as MPR.

Thus, OLSR provides three optimizations to the LSR protocol. First, a smaller number of TC messages is generated due to the fact that only nodes selected as MPRs generate TC messages. Second, OLSR creates TC messages of a smaller size since each TC message includes only nodes that have selected its source as MPR. Finally, OLSR reduces the number of forwarded messages since only nodes selected as MPRs forward messages. However, OLSR is totally agnostic to route quality and considers only the number of hops. We review extensions to OLSR created to overcome this drawback in Sect. 4.

2.2 Advertisement of QoS Information

To estimate the route quality, the resources that each bridge provides to inter-domain communication must be propagated. For each network interface, a bridge defines the bandwidth it wants to share with others as a function of the total available bandwidth for the interface (e.g. 20% of the available bandwidth for interface *eth1* can be used for inter-domain routing). Similarly, each user whose device is acting as a bridge can define a cost for forwarding messages. Different costs can be assigned to different network interfaces by the same bridge, but we consider only symmetric cost schemas, where the cost of a packet transmission via a link $\langle A, B, net1\rangle$ is equal to the cost of a backward packet transmission via a link $\langle B, A, net1\rangle$. Note that control messages are free of charge and this cost is applied only to service provisioning messages. Finally, each node handling a message can introduce delays due to message processing. Each bridge computes its own processing delay according to the memory and processing time it assigns to inter-domain routing. The link delay is the bridge delay plus the delay announced by the neighbor nodes.

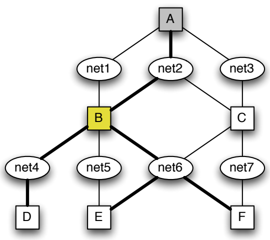
2.3 Multiple QoS Metrics Routing

The B3GQOLSR protocol requires each node to choose two groups among its one-hop neighbors: MPRF, which are the neighbors used to flood control messages through the network, and MPRQ, which are the neighbors that will constitute the routes. As suggested by Nguyen and Minet [14], such division enables the protocol to separate flood control from routing and to use different criteria for selecting nodes to be part of each group.

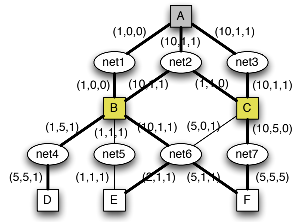
HELLO messages in B3GQOLSR are extended to contain the node's QoS characteristics and the QoS characteristics of its one-hope neighbors, and we can optimize the amount of advertised information by selecting only links with dominating QoS characteristics. For example, in Fig. 2(a) node A can communicate with node B via two networks, $net1$ and $net2$. If all QoS characteristics of $net1$ are better than those of $net2$, there is no need to advertise the link $\langle A, B, net2\rangle$ as it will never be used in any route. Generally, for a pair of neighbor nodes a minimum of 1 (with all dominating QoS characteristics) and a maximum of 3 links (each with one dominating QoS characteristic) will be selected. Finally, in addition to the MPRF set (equivalent to MPR in OLSR), HELLO messages contain also the MPRQ set.

After reciprocal exchange of HELLO messages, each node obtains the complete information about its two-hop neighborhood, including QoS characteristics, and can run MPRF and MPRQ selection algorithms. MPRF selection is analogous to MPR selection in OLSR. Figure 2(a) shows in shad-

[1]Other two types of messages, Multiple Interface Declaration (MID) and Host and Network Association (HNA) are employed for supporting nodes with multiple interfaces and injecting external routing information into OLSR networks.



(a) MPRF set of A



(b) MPRQ set of A

Figure 2: Selection of MPRs by node A

owed boxes the MPRF set of node A: its unique MPRF B covers all its two-hop neighbors D, E and F. Nodes must select the MPRQ set in such a way that each of its two-hop neighbors can be reached by a route with optimal bandwidth, delay or cost. Figure 2(b) shows the advertised values of bandwidth, delay and cost, and the MPRQ set selected by node A.

MPRQ selection considers three different criteria. First, it includes all one-hop neighbors that provide the widest routes (i.e., routes with the largest bandwidth) to all two-hop neighbors (see Fig. 3(a)). Whenever there is a tie, the algorithm selects the fastest and then the cheapest route. This increases the probability that the same node will be selected by further steps of the algorithm and reduces the size of the MPRQ set. Then, the algorithm selects one-hop neighbors that minimize the delay to reach all its two-hop neighbors (see Fig. 3(b)). Finally, one-hop neighbors that minimize the cost to reach two-hop neighbors are selected (see Fig. 3(c)). In those cases, whenever there is a tie the algorithm selects nodes that are already part of the MPRQ set. TC messages are generated by the nodes selected as MPRQs and contain a list of all links to nodes that selected the node as MPRQ. The MPRQ node sends a TC message to all its neighbors but only those selected as MPRF forward it, preserving the flooding optimization of OLSR.

Based on data from HELLO and TC messages, each node can compute its local routing table. First, each node includes into its routing table links with dominating QoS characteristics to each of its one-hop neighbors. After, links between a one-hop and a two-hop neighbor with dominating QoS characteristics are selected and also included. Finally, links extracted from TC messages are included. From this routing table, the node discovers QoS-aware paths to a given destination using a modified Dijkstra's algorithm. In our protocol, (i) the shortest path, (ii) the shortest path with a required bandwidth, (iii) the minimal delay path, (iv) the minimal delay path with a required bandwidth, (v) the cheapest path, (vi) the cheapest path with a required bandwidth, and (vii) the widest path can be provided to a client upon its choice.

2.4 Protocol Properties

Let us show that the B3GQOLSR protocol finds a path with maximal bandwidth among any two nodes A and B in a connected network.

Proof. Imagine that the widest path is **not** discovered by the B3GQOLSR. Let $p_w = (A, N_1, N_2, ..., N_{k-1}, N_k, B)$ be a sequence of nodes on the unique widest path between nodes A and B. The bandwidth $q_B(A, B)$ of this path is $min(q_B(A, N_1), ..., q_B(N_{k-1}, N_k), q_B(N_k, B))$, where we denote the available bandwidth between two neighbor nodes X and Y by $q_B(X, Y)$, and it is computed as the maximal bandwidth among all networks they share. To discover a path from A to B, the Dijkstra algorithm is applied to a graph defined by the local routing table of the node A. Therefore we must prove that the path p_w is not included in this table, that is, there exists a set of neighbor pairs $S = (N_j, N_{j+1}) \in p_w$ for which either no links have been advertised in TC messages or these messages have not reached A. Since we use a mechanism for TC message propagation analogous to that of OLSR, which was proven to be correct [8], we conclude that a TC message advertising a maximal bandwidth link between N_j and N_{j+1} has not been generated, that is, the node N_{j+1} has not selected N_j as its MPRQ. Let (N_i, N_{i+1}) be such a pair closest to A. Let us also consider an MPRQ set selected by the node N_{i+1}. Suppose that it has selected $N_i' \neq N_i$ as MPRQ to cover the node N_{i-1}. From this follows that $q_B(N_{i+1}, N_i', N_{i-1}) = min(q_B(N_{i+1}, N_i'), q_B(N_i', N_{i-1})) \geq min(q_B(N_{i+1}, N_i), q_B(N_i, N_{i-1})) = q_B(N_{i+1}, N_i, N_{i-1})$. Taking into account that q_B is symmetric, we conclude that $q_B(p_w') = q_B(A, ..., N_{i-1}, N_i', N_{i+1}, ..., B) \geq q_B(A, ..., N_{i-1}, N_i, N_{i+1}, ..., B) = q_B(p_w)$, which contradicts our assumption that p_w is a unique widest path between A and B. Therefore, the path p_w will be discovered. $\square$

Here we assumed for clarity that there is only one widest path, but the assumption that none of the existing widest paths is discovered can be shown to be contradictory in a similar way. The proof that the protocol finds paths with minimal delay and minimal cost is analogous.

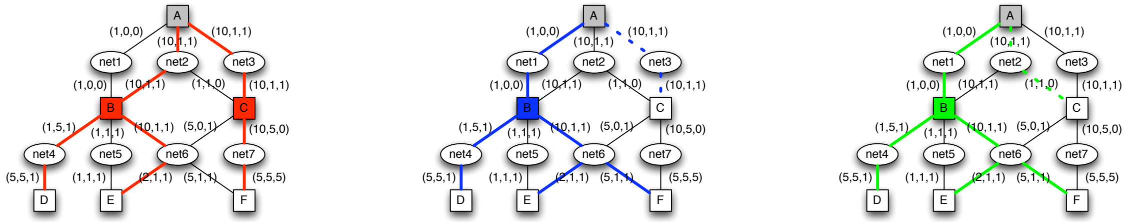
3. EVALUATION

Our routing protocol is implemented as part of the PLASTIC middleware [7]. The PLASTIC project[2] aims at facing the challenges of software development for infrastructure-less B3G environments by creating (1) tools that facilitate service design and development, (2) a service-oriented middleware that provides features to enhance and ease application adaptation to mobility, and (3) a framework for off-line and on-line validation of B3G services. To handle user mobility, the PLASTIC middleware implements an additional addressing scheme called MNR@, which is associated to all active IP addresses of a host and managed by the middleware's Mobility Management component. With MNR@, B3GQOLSR enables routing in multi-homed environments without the overhead of *Multiple Interface Declaration* (MID) messages.

To evaluate our protocol, we created 10 random networks containing 10 to 50 bridges, on a total of 50 different topologies. Each bridge is connected to a random number of networks from 1 to 4, reproducing a scenario where devices have up to 4 different network connections. For each technology, 3 profiles containing different values of bandwidth, delay and cost are considered and the mapping between interfaces and profiles is also random.

The goal of the evaluation is to measure the control traffic overhead of B3GQOLSR compared to LSR and OLSR. Each bridge runs the three routing protocols for 5 minutes. All

[2]http://ist-plastic.org/



(a) The widest paths (b) The fastest paths (c) The cheapest paths

Figure 3: Details of MPRQ selection by node A in a B3G environment

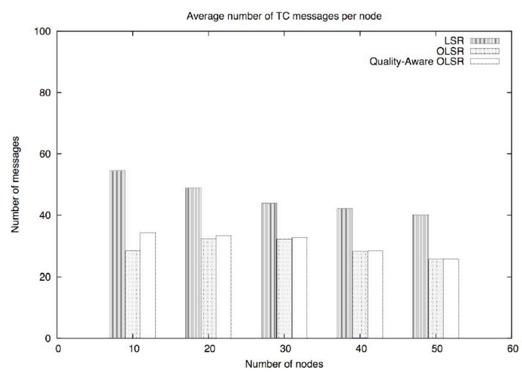


Figure 4: Average number of TC messages

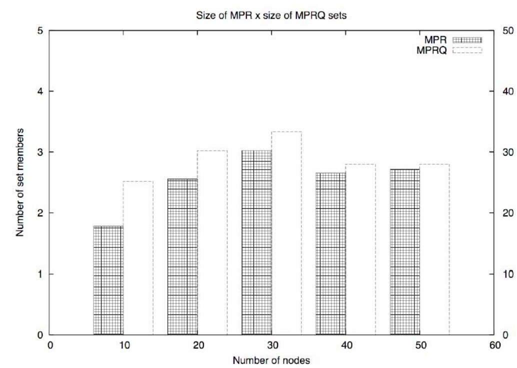


Figure 5: Average sizes of MPR and MPRQ sets

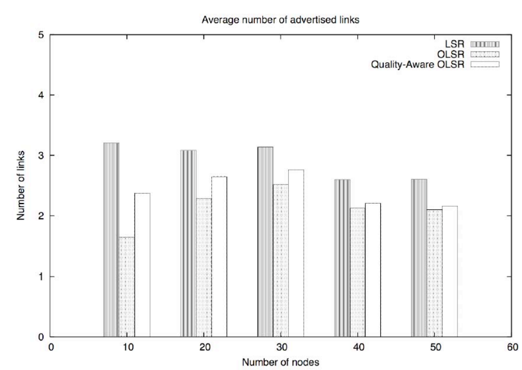


Figure 6: Average number of advertised links

nodes send HELLO messages every 2 seconds and TC messages every 5 seconds (as recommended by the OLSR specification [1]). The state of neighbor nodes is also checked every 5 seconds. We compare the number of topology control (TC) messages generated in average by network nodes and the number of advertised links in average for each of the examined protocol. We also compare the average size of OLSR MPR sets with the average size of the MPRQ sets generated by B3GQOLSR.

Figure 4 shows the number of topology messages generated by LSR, OLSR and B3GQOLSR. We can see that the number of B3GQOLSR topology messages is closer to the number of messages generated by OLSR than by LSR.

MPRQ members generate TC messages containing the list of its MPRQ members, so a larger MPRQ set means that each topology message has a bigger size. Figure 5 shows the average sizes of the OLSR MPR sets and the B3GQOLSR MPRQ sets. The average size of both sets is similar, with MPRQ being a little bigger. This overhead is acceptable if we consider the protocol benefits. The size of topology messages in B3GQOLSR is comparable to the size of TC messages in OLSR.

Finally, Fig. 6 compares the average number of links advertised by each protocol and shows the benefits of our approach. The original LSR advertises all available links and can be considered as the maximum. OLSR, on the other hand, keeps a single path between any two nodes. In all cases, the number of links announced by B3GQOLSR was greater than with OLSR, which shows that in all topologies there were links with either greater bandwidth, smaller delay or smaller cost that were ignored by OLSR. Our protocol, thus, enables users and applications to find better routes than those announced by OLSR.

4. RELATED WORK

In this section, we provide an overview of the research in the areas of QoS management in B3G environments and QoS-aware extensions of OLSR.

A number of existing works aim at integrating wireless LANs into cellular networks by incorporating wireless routers to the operator infrastructure. The architecture proposed by [13] assumes that the operator also manages the wireless routers and proposes QoS-management to be performed on the operator-side. The architecture proposed by [17] is more flexible, and enables the connection of WLANs administered by the operator, shared between operators and managed by the customer. However, they assume corporate customers with infrastructure-based and stable networks. Finally, the architecture proposed by [5] supports integration of tightly- as well as loosely-coupled WLANs, but it focuses essentially on the connection between structured WLANs to the core cellular network. The protocol proposed in our paper is targeted at integrating administratively independent and mobile networks. The ACENET architecture [16] assumes a more dynamic and heterogeneous mobile system that combines cellular, wireless and ad hoc networks. Routes to access stable nodes are proactively maintained while routes between any two mobile nodes are discovered on demand. By considering the combination of heterogeneous networks as a single large network, the protocol increases the complexity of routing in B3G since it has to compute routes between any two mobile nodes. We propose an architecture that simplifies routing by separating intra-domain from inter-domain routing.

Several approaches have been developed to introduce QoS support in OLSR, selecting MPRs according to bandwidth [6] or delay [9] for example. Those approaches, however, may increase the size of MPR sets and thus increase flooding of TC messages. Nguyen and Minet [14] avoid this side effect by separating flooding (MPRF set, selected as in OLSR) from routing (MPRB set, selected according to bandwidth), which preserves the OLSR flooding optimization. Aslam et al. [2] propose a composite metric including bandwidth, delay and jitter, but it does not guarantee the optimality of the routes regarding any single metric. Instead of combining metrics, QOLSR [3] proposes optimization of one metric (e.g., bandwidth), and other metrics only in case of multiple optimal routes. The main drawback of these approaches is that their optimization criteria is protocol-defined and not user- or application-defined as in our extension.

5. CONCLUSION

In this paper, we presented a protocol for QoS-aware routing in infrastructure-less B3G environments. Our protocol enables discovery of the routes with optimal bandwidth, delay or cost, depending on the user preferences for a given communication. We have presented the protocol, proved its properties and compared its performance to OLSR and LSR for several network topologies.

In our future work, we plan to use historical information about node availability and trust as additional criteria to select MPRQ nodes. This would permit a node to dismiss the quality information announced by a node with bad reputation. It would also enable selection of nodes that historically present good availability. We also plan to integrate an admission control mechanism to the protocol for enabling bandwidth reservation for a given communication.

6. ACKNOWLEDGMENTS

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7. REFERENCES

[1] S. Adjih et al. Optimized Link State Routing Protocol. RFC 3626, IETF, 2002.

[2] N. Aslam, W. Phillips, and W. Robertson. Composite Metric for Quality of Service Routing in OLSR. In *Proc. of the Canadian Conf. on Electrical and Computer Engineering*, 2004.

[3] H. Badis, A. Munaretto, K. A. Agha, and G. Pujolle. QoS for Ad hoc Networking Based on Multiple Metrics: Bandwidth and Delay. In *Proc. of the IFIP-TC6 Int. Conf. on Mobile and Wireless Communications Networks*, 2003.

[4] R. S. Cardoso, P.-G. Raverdy, and V. Issarny. A Privacy-Aware Service Discovery Middleware for Pervasive Environments. In *Proc. of the Joint iTrust and PST Conf. on Privacy, Trust Management and Security (IFIPTM'07)*, 2007.

[5] R. Ferrus et al. A Feasible Approach for QoS Management in Coordinated Heterogeneous Radio Access Networks. In *Proc. of the IEEE Int. Conf. on Performance, Computing, and Communications (IPCCC'05)*, 2005.

[6] Y. Ge, T. Kunz, and L. Lamont. Quality of Service Routing in Ad-Hoc Networks Using OLSR. In *Proc. of the Annual Hawaii Int. Conf. on System Sciences (HICSS'03)*, 2003.

[7] V. Issarny et al. PLASTIC Deliverable 3.1: Middleware Specification and Architecture. PLASTIC Deliverable, 2007.

[8] P. Jacquet et al. Optimized Link State Routing Protocol for Ad Hoc Networks. In *Proc. of the IEEE Int. Multi Topic Conf. (INMIC'01)*, 2001.

[9] K. J. Lee, M. S. Kim, S. Y. Cho, and B. I. Mun. Delay-Centric Link Quality Aware OLSR. In *Proc. of the IEEE Conf. on Local Computer Networks (LCN'05)*, 2005.

[10] J. Liu and V. Issarny. An Incentive Compatible Reputation Mechanism for Ubiquitous Computing Environments. *International Journal of Information Security*, 6(5), 2007.

[11] W. Mohr and R. Becher. Mobile Communications Beyond Third Generation. In *Proc. of the 52nd Vehicular Technology Conf. (VTC'2000)*, 2000.

[12] N. Natarajan. On Systems Beyond 3G: Requirements and Approaches. In *Proc. of the Int. Conf. on Communication Technology (ICCT'03)*, 2003.

[13] M. L. Needham and N. Natarajan. QoS in B3G Networks - An Overview. In *Proc. of the Int. Conf. on Communication Technology (ICCT'03)*, 2003.

[14] D.-Q. Nguyen and P. Minet. QoS support and OLSR Routing in a Mobile Ad hoc Network. In *Proc. of the Int. Conf. on Networking, Int. Conf. on Systems and Int. Conf. on Mobile Communications and Learning Technologies (ICNICONSMCL'06)*, 2006.

[15] C. Perkins, E. Belding-Royer, and S. Das. Ad hoc On-Demand Distance Vector (AODV) Routing. RFC 3561, IETF, 2003.

[16] C.-H. Yeh. ACENET: Architectures and Protocols for High Throughput, Low Power, and QoS Provisioning in Next-Generation Mobile Communications. In *Proc. of the IEEE Int. Symposium on Personal, Indoor and Mobile Radio Communications*, 2002.

[17] W. Zhuang, Y.-S. Gan, K.-J. Loh, and K.-C. Chua. Policy-based QoS Management Architecture in an Integrated UMTS and WLAN Environment. *IEEE Communications Magazine*, 41(11), 2003.