QOS-AWARE POLICY BASED ROUTING FOR MESH NETWORK ENVIRONMENTS

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Abstract: The design of a policy oriented configurable multi-path routing architecture for enhanced mesh network infrastructures is discussed. The goal is optimal routing path selection between mesh clients and mesh router gateways dependent on application classes. Policies are used to dynamically configure the route path selection for QoS-aware applications taking into account resource reservation requests for application traffic (in advance reservation, on-demand resource allocation, etc) and business goals of the policy actors, i.e. end-users, service providers and network operators. Interactions of the mesh routing protocol facilities with the policy management and resource planning components for advance and on-demand resource allocation are considered. Scenarios are aimed at supporting QoS-aware applications (such as IPTV, VoD, GRID, VoIP, real-time, mission critical, content delivery on-demand, software and large file downloads) using a wireless mesh network backbone infrastructure (based on IEEE 802.11, IEEE 802.16) enhanced with broadcast technologies (DVB-T, DVB-H).

1 INTRODUCTION

Wireless mesh networks are promising solution for a number of emerging scenarios – broadband home networking, "city" community, neighbourhood, transportation, health and medical networking systems (Akyildiz et al., 2005). In the new business models for wireless mesh network infrastructure, it is a challenge to support a wide range of QoS-aware applications with specific resource and delivery requirements, such as IPTV, VoD, GRID, VoIP, real-time, mission critical, content delivery on-demand, software and file downloads. The interest of providers and operators is to efficiently use the wireless mesh infrastructure considering the dynamic resource requirements of QoS-aware applications and the optimisation of the routing for different kind of application traffic.

Resource requests can be focussed on selection of most the appropriate network and router, resource reservation in advance, on-demand reservation, reservation with different level of QoS guarantees (Hetzer et al., 2006) and others. There is a need for new management strategies including interactions of resource management and routing facilities in order to enhance the QoS guarantee depending on the specific application resource requests in heterogeneous wireless mesh environments.

In this paper, a QoS-aware policy routing architecture is proposed, which is aimed at flexible support of QoS-aware Internet applications in heterogeneous networking environments dependent on the policies of end-users, service providers and network operators. The particular focus is the design of components and their interactions for QoS-aware policy routing in wireless mesh infrastructures (IEEE 802.11, IEEE 802.16) enhanced with broadcast technologies (DVB-T, DVB-H).

With the synergy of the broadcast and Internet worlds, there is an increasing demand for routing facilities considering the specifics of broadcast networks and their cost-efficient usage for specific kind of applications (Near-Video-on-Demand, IPTV, content delivery). In order to support efficient resource usage and enhanced QoS, policy based multi-path routing facilities for QoS-aware applications are proposed, which use resource

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(bandwidth) planning and QoS/SLA monitoring information collected at the mesh router gateways.
This paper is organised in the following sections. Section 2 evaluates QoS issues of current routing protocols for wireless mesh network infrastructure. Section 3 discusses components for QoS-aware policy routing. Section 4 describes a scenario based on a wireless mesh infrastructure enhanced with broadcast media. In section 5, a policy management interface for flexible QoS routing configuration is discussed. Section 6 concludes this paper.

2 POLICY ROUTING FOR WIRELESS MESH NETWORKS

The routing in wireless mesh networks is primarily based on the concepts of routing protocols for ad-hoc infrastructures. In order to support QoS-aware routing of value added services and applications with specific QoS requests, the routing protocols can be enhanced with policy based routing strategies.

2.1 Routing Protocols

IP has been accepted as network layer protocol for integration of wireless mesh networks.
Wireless mesh networks can be deployed as infrastructure/backbone and client architectures connected to the Internet. The connectivity of the mesh infrastructure / backbone to the Internet core is based on mesh gateways. Mesh routers are forming a multi-path routing infrastructure for mesh clients to the mesh gateways (Akyildiz et al., 2005) (figure 1).
Actual requirements for routing in wireless mesh networks are support of alternative (multiple) routing paths, efficient resource usage, support of QoS routing in heterogeneous environments, as well as enhanced routing reliability.

For the interconnection and routing in mesh network environments, different protocols developed for mobile ad hoc networks can be efficiently applied (Conti et al., 2007). Such protocols are for instance:

- On-demand Distance Vector Routing (AODV) (Perkins et al., 2003).
- Topology dissemination based on reverse path forwarding (TBRPF) (Ogier et al., 2004),
- Dynamic Source Routing (DSR) [6],

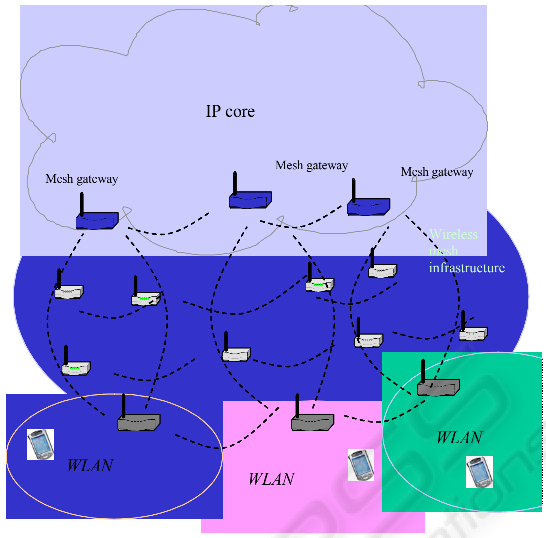

Figure 1: Wireless mesh infrastructure.

Algorithms and protocols for mesh routing can be classified depending on their mechanisms and applications into:

- *On-demand routing* protocols, which create a route between a pair of source and destination nodes, when the source node actually needs to send packets to the destination (see, DSR (Johnson et al., 2004);
- *Proactive Routing Protocols*, where each node maintains one or more tables containing routing information to every other node in the network. According the method for forwarding packets along routes, the proactive routing differentiates between source routing (for instance, Link Quality Source Routing – LQSR (Draves et al., 2004)) and hop-by-hop proactive routing.

Intelligent mechanisms for dynamic routing optimisation in mesh network infrastructures can be integrated in order to analyse routing stability, improve performance and load balancing, as well as to support autonomic design considerations.
ROMER (Resilient Opportunistic Mesh Routing Protocol), for example, is a routing protocol balancing between long term route stability and short term opportunistic performance (Yuan, et al., 2005).
Dependent on application and business goals, the efficiency of the routing algorithms can be evaluated in terms of performance metrics (Yang, et al., 2005). Such metrics are blocking probability by attempting several routes in parallel, protocol overhead for selection of specific routes (routes with maximum QoS guarantee and with minimal cost), route recovery time in case of failure.

2.2 QoS-aware Policy Routing

The design of QoS-aware policy routing depends on the application (business goals and scenarios), as well as on the specific structure of the infrastructure. Policy oriented routing mechanisms for Internet protocols are discussed in RFC 1102 (Clark et al., 1989). To support specific business goals and policies, the design of QoS-aware routing for mesh networks can be based on *application and overlay routing techniques* (see (Shi et al., 2002), (Kwon et al., 2002), (Zhang, et al., 2005)).
Overlay routing protocols can be designed for different topologies – full mesh, minimum spanning tree, mesh-tree, adjacent connections (Li et al., 2004). Algorithms for multi-path routing combined with reserving resources in parallel along several routes connecting end-users are discussed in (Cidon, et al. 1998).Resilient Overlay Network (RON) (Andersen, et al., 2001) is an example for sophisticated policy routing considering source traffic type and application class. The policy routing is separated into two components – *classification and routing table formation.* The policies allow the detection and recovery from path outages and periods of decreased performance. Further related work is aimed at scalable Distributed Object Location and Routing overlay services exploiting existing network redundancy by dynamic switching of traffic onto pre-computed alternative routes (Ratnasamy et al., 2001), (Rowstron et al., 2001).
The QoS-aware policy routing design proposed in this paper is based on the overlay technique and implies interaction of resource planning and routing facilities.

3 POLICY BASED ROUTING ARCHITECTURE

The proposed multi-path QoS routing facilities are based on dynamic configuration and adaptation of routing tables for application traffic using policies of different actors – end-users, service providers and network operators. The policy framework is designed to consider different resource reservation strategies for applications, such as:

- On-demand and planned reservation,
- Selection of networks and routers dependent on application criteria,
- Bandwidth planning and monitoring information at the mesh gateways.

3.1 Policy Definition

The policy model for QoS-aware routing is based on IETF policy framework, especially RFC 3060 (Moore, et al., 2001), RFC 3640 (Moore et al., 2003), RFC 3644 (Snir, et al., 2003).
A policy consists of a set of rules defined by the policy actor. The rules are specified for different application classes using condition and actions.
A policy rule P for the QoS-aware routing is set by:
$P := C\ (\underline{App}\ X\ \underline{Act}\ X\ \underline{Res}) \rightarrow A\ (G\ X\ \underline{Rt}\ X\ \underline{B})$, where

- C is a condition defining resource reservation options for application classes and policy actors:
- App is the set of specified application classes;
- Act describes the profiles of the policy actor;
- Res is the set of possible resource reservation strategies;
- A is action updating the routing and resource planning tables at the mesh gateways;
- Rt is the set of routing tables;
- G is graph describing the topology of the wireless mesh infrastructure;
- B is the set of bandwidth plans for the mesh gateways.

The different reservation strategies depend on the specific traffic classes, such as content delivery, file downloads, media streaming (IPTV and VoD), GRID, real time mission critical and voice over IP. Examples for different kind of resource reservation strategies, which can be used in the policy specification for the QoS-aware policy routing, are given in figure 2:

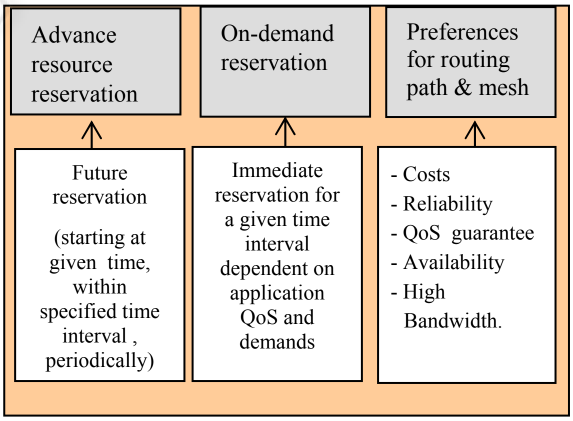

Figure 2: Resource reservation strategies.

3.2 Functional Design

The architecture is based on existence of alternative routes between mesh clients and gateways of a wireless mesh infrastructure / backbone (see, figure 1). The configurable routing path selection is using the specified policies of the different actors in order to select dynamically the optimal routing path and mesh gateway for the particular application.

Based on a common policy repository, different components are interacting:

- Policy management system enforcing the facilities for route table configuration and bandwidth planning / monitoring;
- Facilities for automated routing table configuration at the routers of the mesh infrastructure;
- Toolkits for QoS/SLA monitoring and bandwidth planning at the mesh gateways.

Interfaces between these components allow the dynamic reconfiguration of the routing information for the application classes and the adaptation of the bandwidth planning information at the mesh gateways based on the specified policies.

The functional design and the interactions of the components are shown in figure 3.

Using management interfaces, the different actors enter the policies into the system.

The policies are checked for consistency, translated and stored in policy repositories.

Because the policies are set by different actors, their parameters (specified by conditions and actions) can be automatically changed by the Policy Decision & Adaptation Manager according the hierarchical relationships of the actors (end-users, service providers and network operators) and their QoS/SLA for the application classes. Furthermore, based on the feedback of the bandwidth reservation planning and QoS/SLA monitoring data at the mesh gateways, the policies can be dynamically adapted and optimised by the policy decision manager.

In order to trigger the final policies, the policy enforcement manager interacts with the routing and bandwidth planning components. The results can be:

- Dynamic configuration of the routing tables of the infrastructure for application classes based on the specified policies;
- Bandwidth plan updates at the mesh gateways according the selected routing paths.

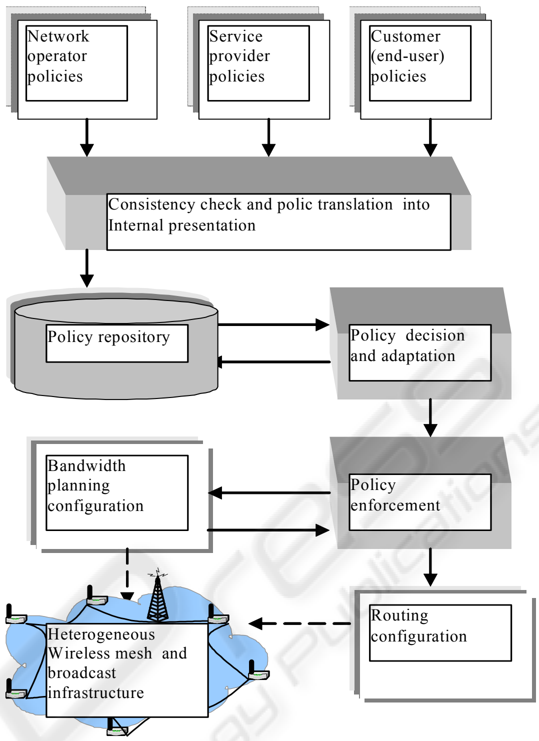

Figure 3: Functional design of QoS policy routing.

For the bandwidth planning and QoS/SLA monitoring, the QORE system for advance resource reservation can be used, which supports the bandwidth planning for different kinds of application classes and scenarios at the routers of networking infrastructures (see (Hetzer et al. 2006), Miloucheva et al. 2007)).

4 SCENARIO

A simple scenario for multiple path routing aimed at providing enhanced QoS-aware policy routing for multimedia content delivery of streaming content (Video-on-Demand, TV channels, news, advertisement, software downloads) is shown. The scenario is based on infrastructure / backbone wireless mesh networks (WLAN IEEE 802.11, WIMAX IEEE 802.16) enhanced with broadcast media (DVB-T, DVB-H) connected to the core Internet (see figure 4). Using policies, the users can optimise the routing path for the multimedia content delivery dependent on the resource reservation strategies of the application.

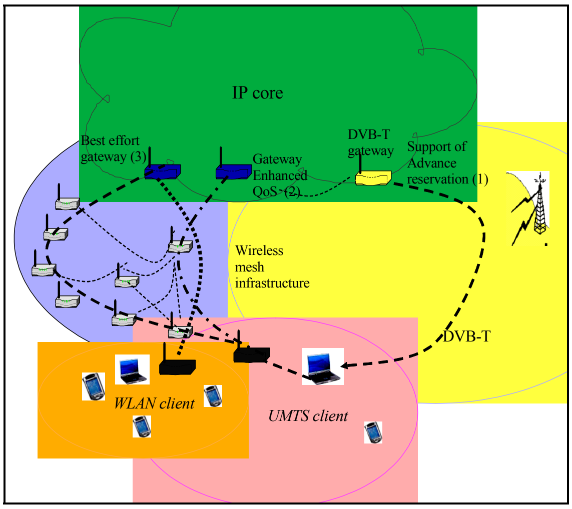

Figure 4: Scenario for QoS-aware policy based routing.

In the scenario, different routing paths are possible for application classes dependent on the specific requirements of the users:

- The user specifies *"advance reservation" strategy* defining the delivery time for planned and periodical applications. For instance, fixed time can be specified for a requested TV program, multimedia conference or entertainment / remote teaching applications. Future time interval (earliest or latest delivery) can be requested for applications, such as Video-on-Demand (VoD) and file downloads.
- The immediate reservation of resources is specified by *"on-demand" resource* reservation strategy. This strategy can be used for unplanned delivery of content and mission critical applications.
- When a user requests "best effort" service, an appropriate gateway is selected by the policy system and assigned for routing of the application. Minimal QoS guarantees are provided for the user traffic.

Assuming that for the multicast and multimedia content delivery applications with "advance resource reservation" requests, the routing is specified using the mesh gateways for the DVB-T networks.

The path selection can be dynamically changed for particular user profile and application class depending on further policies aimed at "cost efficiency", "reliability", "high QoS provision".

The benefit is that the routing paths can be selected and dynamically changed according to the policies of the different actors (end-users, service providers and network operators) and their dependencies.

5 POLICY MANAGEMENT INTERFACE

The routing policies in wireless mesh infrastructures considering QoS-aware applications are specified based on parameters and options using appropriate Graphical User Interfaces (GUIs) for users, service providers and network operators.

Policy management interfaces allows specification of policy parameters, check of policy dependencies considering actors relationships and policy translation into internal policy presentations.

An example of a GUI for dynamic selection of appropriate routes for QoS-aware applications using policy translation is shown in figure 5.

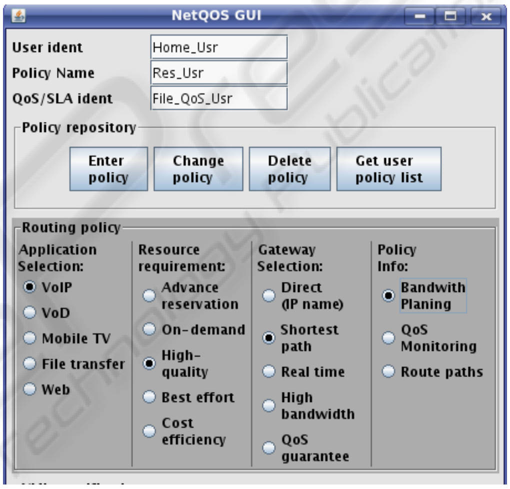

Figure 5: User interface for policy based routing.

The policy is identified by the policy name, policy actor profile and QoS/SLA. The parameters of this interface are related to ontology based domain descriptions, based on which the relationships between the parameter values are obtained.

The policies are translated into the internal policy repository representations. The policy repository functions allow the performing of operations for entering, changing, deleting of policies, as well as browsing of policies based on the policy repository. Policies can be retrieved from the repository and dynamically adapted using learning algorithms.

Conditions and actions of the routing policies are specified by a set of parameters describing

- Application/Services, which are using the routing infrastructure;
- Resource reservation strategy;
- Gateway requirements.

The actions (change of routing table information and bandwidth plans at the mesh gateways) are automatically configured by the systems.

In the given example, the management interface allows the selection of the application class (VoIP, VoD, Mobile TV, File Transfer, Web). The resource reservation strategy for the particular application is specified by options for ”Advance resource reservation”, “On-demand reservation”, “HighQuality” or “Best effort”. The routing requirement is given by the “Shortest path” option.

6 CONCLUSIONS

A QoS-aware policy routing architecture based on the interaction of policy management, routing and bandwidth planning components for wireless mesh infrastructures was proposed. The benefit is flexible configuration of routing tables for routing depending on application resource requests. This allows cost efficient routing per application class considering wireless mesh and broadcast media networks. Particular advantage of the architecture is dedicated usage of broadcast media for specific multicast and multimedia applications. The proposed design is based on the policy management framework developed in the EU IST project NETQOS.

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