Seamless Connectivity Platform Architecture for Public Transportation

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Introduction

Motivation

Next Generation Networks have to:
- use multiple wireless access technologies;
- support generalized mobility;
- the users have to be Always Best Connected.

Ubiquitous communication in heterogeneous networks requires new architecture elements and algorithms capable of:
- cross-layer operations;
- Network State Information (NSI) acquisition and processing;
- efficient radio resource management.

One possible application is in smart public transportation:
- communication services for the passengers;
- benefits for transport companies.
Basic Principles

Characteristics of seamless connectivity solutions for public transport:
- energy efficiency is not the main target, but it is important;
- transmission device of the vehicle has several wireless interfaces;
- loose coupling between the operator’s core networks.

We propose the architecture design on 3 distinct levels:
- system architecture;
- functional architecture;
- platform architecture.

System architecture elements:
- Smart Mobile Router (SMR);
- Application Server Platform (ASP) formed of:
  - Ubiquitous Connectivity Support Server (UCSS);
  - Service Continuity Gateways (SCG).
**System Architecture Overview**

*Figure: Ubiquitous connectivity system architecture.*
System Architecture Details

Smart Mobile Router (SMR):
- installed in the vehicle offers Internet access;
- with access control and authentication functions;
- equipped with several wireless interfaces;
- selects the target network for handover and load balancing;
- measures and processes the NSI and flow parameters.

Application Server Platform (ASP):
- assists the SMRs in providing ubiquitous connectivity over several wireless networks.
System Architecture Details

Ubiquitous Connectivity Support Server (UCSS):
- gathers, processes and stores the context information (CI) from the SMRs;
- distributes the centralized CI among the SMRs.

Service Continuity Gateway (SCG) assists the SMRs in:
- offering ubiquitous connectivity;
- active measurements of delay, available transfer rate, etc.

The handover (HO) and load balancing (LB) operations can be combined into a single process:
- better connectivity;
- improved user experience.
SMR Functional Architecture Overview

Figure: Functional architecture of the SMR.
SMR Functional Architecture Details

Communication subsystem = Information Forwarding Subsystem: acts as a switch, allows the architecture modularization and easy subsystem integration.

Configuration subsystem = Configuration Interface Subsystem: allows to specify the policies controlling the HO & LB operations and the QoS requirements.

Data storage subsystem = Local Database (LD) Subsystem: stores the acquired NSI and the CI downloaded from the Central Database (CD).

Authentication Subsystem: allows the SMR to get authenticated and authorized in the operator’s networks.

Figure: Authentication subsystem.
**SMR Functional Architecture Details**

**Decision subsystem** = HO and LB Manager uses the acquired NSI:
- HO Decision Module controls the VHO process;
- LB Decision Module controls the possible load balancing operations.

**Execution subsystem** = Connection and Mobility Manager:
- HO & LB Execution Module selects and switches data flows between IP paths;
- NAT Control Module creates new logical IP paths.

**Figure**: HO & LB Manager subsystem.
Operation support subsystem = Context Information Manager Subsystem including the modules dealing with:

- NSI;
- service;
- flow related information acquisition and storage.

Figure: CI Manager subsystem.
SCG Functional Architecture

The functional architecture of the SCG is similar with that of the SMR’s.

The main differences are:

- the lack of the HO & LB Manager Subsystem and of the Authentication Subsystem;
- no decision is taken by the SCG concerning the HO and LB operations;
- the CI Manager Subsystem has a simplified structure, it only helps the SMR in performing active measurements.
SMR Platform Architecture Overview

Figure: Platform architecture of the SMR.
SMR Platform Architecture Details

SMR implemented on a microcomputer with minimal Linux OS.

The **HO & LB Manager Subsystem**, the **Connection & Mobility Manager Subsystem**, the **Authentication Subsystem** and the **Configuration Interface Subsystem** map on individual software modules.

**CI Manager Subsystem** maps on several software modules:

- the monitoring modules of the wireless interfaces, GPS receiver and data flows;
- LD and CI Handler module processes and stores the NSI in the LD;
- Local Database module.
SMR Platform Architecture Details

The hardware monitoring module identifies the potential operational issues or malfunctioning.

The mapping of the functional architecture on the platform architecture is based on:

- **functional** criteria:
  - the monitoring modules quickly detect any changes in the network or hardware state;
  - the routing modules promptly react to the commands;
  - the decision modules predict changes in the network or system state;
  - the CI handling and storage modules have less stringent time constraints;

- **nonfunctional** criteria:
  - the portability of the SMR platform.
SCG Platform Architecture Overview

![Platform Architecture Diagram]

**Figure**: Platform architecture of the SCG.

- **Service Continuity Gateway Platform**
  - Hardware Monitoring Module
  - WiFi Measurement Module
  - Cellular Measurement Module
  - GPS Module
  - Information Forwarding Subsystem
  - Interoperability Module
  - Connectivity Manager
  - Context Information Manager Subsystem
  - Connection & Mobility Manager Subsystem

Internet
SCG Platform Architecture Details

SCG implemented on a high performance computer platform.

The platform architecture of the SCG:
- Connectivity Manager Module implements the routing operations;
- WiFi and the 2G/3G/4G Measurement modules work with the SMR’s wireless Monitoring modules to perform active measurements;
- GPS Module used for synchronization purposes;
- Hardware Monitoring Module monitors the SCG hardware functioning.

The mapping of the SCG’s functional architecture on the software architecture is similar to the SMR.
NSI and Flow Parameter Acquisition

3 categories of NSI:

- link parameters (e.g. signal strength, SINR, etc.);
- traffic parameters (e.g. transmitted/received packets, traffic class, etc.);
- and network parameters (e.g. Service Set Identifier, operator name, etc).

Monitoring of the WLAN parameters is based on the *iw* tool integrated in Linux OS.

Monitoring of the cellular network interface can be achieved by using specific *AT* commands or the *QMI* (Qualcomm Mobile Station Modem Interface) protocol.

The flow monitoring and traffic analysis is based on the *libnetfilter_conntrack* library.
Monitoring Modules

**Operating System’s User Space**

- **WiFi Monitoring Software Module**
  - WLAN-specific Linux commands
  - Standard output replies
  - WiFi specific function calls
  - WiFi Interface Driver
  - WiFi Network Card

- **GPS Monitoring Software Module**
  - Standard Linux commands
  - Standard output replies
  - Driver/Interface specific commands & replies
  - GPS driver
  - GPS receiver

- **Flow Capture & Traffic Analysis Software Module**
  - NTP Daemon (ntpd)
  - Standard Linux commands
  - Standard output replies
  - Network cards

- **Cellular Monitoring Software Module**
  - NTP Daemon (ntpd)
  - AT commands
  - Standard output replies
  - qmi specific commands
  - Standard output replies
  - qmicli
  - qmi-network
  - cdc-wdm Driver

- **Virtual COM Ports**
  - Modem COM Port
  - Application COM Port
  - Diagnostic COM Port
  - Virtual COM Ports
  - Network cards
  - 2G/3G/4G Interface Driver
  - 2G/3G/4G Network Card

**Figure**: The monitoring modules of the SMR.
Module Integration

The Interoperability Module is composed of multiple threads. For each connected software module a dedicated thread is created. The communication is based on IPC sockets. Each software module has a unique ID within the platform.

**Figure:** Module and subsystem integration.
Routing over Heterogeneous Networks

Virtual Private Network tunnels are created between the SMRs and the SCG using the *OpenVPN* software.

The data flows are forwarded through the tunnels based on the decisions taken by the HO & LB Manager module.

Multiple virtual routing tables are created for the connections using the *iptables* tool.

**Figure : VPN Tunnels.**
Conclusions and Future Developments

Architecture design is proposed involving:

- system;
- functional;
- platform architectures of a ubiquitous connectivity system for the public transportation.

Future developments:

- implementation of more complex solutions for ubiquitous connectivity provisioning in vehicular scenarios;
- optimal selection of the VHO target network can be implemented;
- load balancing and other interoperability algorithms can be implemented.
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