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### Users' QoS driven radio resources optimization based on radio environment map

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Abstract. The over the top service optimization in wireless networks is a challenging task due to the diversity of wireless terminals, variety of required quality of service requirements and diversity of wireless service access networks. In this paper, we propose an approach to optimize the allocation of users to wireless networks or even particular cells based on the wireless network exposed radio environment status. The radio cells collect the radio environment status based on terminal measurements and pre-calculated interference maps. It exposes the required information to the over the top service provider. The users are allocated applying the network/cell priority list or using a genetic optimization algorithm. The simulation results reveal that the pico-to-macro cell priority list deterministic approach outperforms macro-to-pico priority list approach, while the genetic based optimization approach slightly outperforms both deterministic approaches.

#### **1. Introduction**

Over-the-top service (OTT) refers to a class of real-time services that operate over the Internet. Consumers and business users make a contract directly with an OTT service provider (OTP), which applies one or more network service providers (NSP) to achieve the required quality of service. The provision of OTT services through the radio access networks is challenging in particular due to (1) radio access network diversity in term of capacity, delay, coverage, cost of service provision and highly dynamic radio environment, (2) plethora of OTT services relying on broadband and narrowband communications, and (3) variety of wireless terminals with different communication and processing capabilities. In order to maximize the user satisfaction with the service provided, the OTT service provider needs to be informed about the wireless terminal capabilities and needs to participate in the resource management of the network service providers.

Currently, the wireless network providers have full control over the network resource management of their networks. However, the emerging network service chaining approach, which allows wireless network adjustment based on service demands using service chains, can be employed [1]. The service chains are a set of service functions which define the way how packet flows are treated while processing by network elements. Currently, the network service providers have a complete control over the network service chains. Consequently, the OTT providers cannot control the application key performance indicators (KPI). In order to provide offered OTT application, the OTT service provider should interact with the network service provider. This interaction requires that the network service providers expose their service capabilities [1]. The third Generation Partnership Project, "Technical Specification Group Services and System Aspects; Architecture Enhancements for Service Capability Exposure" [2], specify the service capability exposure function concept. However, the specified application programing interfaces specified in [2] is not sufficient to perform OTT service

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optimization, thus in this paper we propose to use a radio environment map (REM) for optimization of the OTT services.

REM is an intelligent database that provides a service to the OTT service providers for optimization of offered services. Its functional architecture initially proposed in the FARAMIR project [3], [4], [5] is redesigned to be applied for our purposes. The REM database is updated by the network service providers, OTT provider and measurements obtained from user terminals to be efficiently applied for OTT service optimization. In this paper we propose a REM based network management architecture for OTT service provisioning. We also include differential evolution for multi-objective optimization (DEMO) algorithm and its parallelized asynchronous master-slave DEMO (AMS-DEMO) algorithm to show the gain of optimization of OTT services and the interaction of OTT service providers with the network service provider via creation of network service chains using software defined networks and network function virtualization approach.

The paper is organized as follows. In the next section the architecture of the OTT service optimization is given and REM functional configuration is described. Short overview of the DEMO and AMS-DEMO algorithm with the objective function definitions is given in Section III. In Section IV the simulation scenario is described while the results are analyzed in Section V. Finally, some concluding remarks and outline for further work is provided in the conclusion.

#### 2. Over-the-top service REM supported optimization architecture

The over-the-top service REM supported optimization architecture is depicted in figure 1. The main task of the OTT service provider is to allocate the users to NSPs according to the network capabilities and user requirements. In order to fulfil user requirements in a highly dynamic wireless network environment, the OTT service provider has to be informed about the status of the radio network at a particular user location. Each NSP monitors its networks and it can estimate interference maps, which gives the carrier to noise interference ratio (CINR) at a particular location, assuming the additive Gaussian noise generated at any terminal does not exceed the value specified by the applied radio standard. The estimation of the maximum bandwidth efficiency, which can be achieved at a particular location, is straightforward by using Shannon capacity and adding implementation loss and bandwidth efficiency limits due to the applied coding modulation schemes and hardware limitations. Furthermore, knowing the mobile terminal precise location, its speed and local environment, the link quality can be roughly estimated and afterwards updated based on the measurements provided by the mobile terminals.



Figure 1. Over-the-top service REM supported optimization architecture.

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It has to be emphasized that in this context we do not assume the same architecture of REM or geolocation database as proposed for a cognitive radio approach, but rather a set of raster maps and databases with different tables and procedures to generate, update and process the raster maps and data from the database. We assume a distributed REM where each cell maintain its own REM, containing information about the radio environment covered by a particular cell including path loss maps, CINR maps, bandwidth efficiency maps, link quality maps, and the necessary database for proper operation of the particular cell.

We assume that each network provider maintains its own REM. The radio coverage maps, interference maps and user allocation tables are calculated and maintained for each cell separately. In order to support OTT provider decision on the user to the network allocation, the network status information is fused and exposed to OTT service providers. We propose two levels of wireless network status exposure, namely:

- Network level status exposure, where the OTT service provider obtains information about the available data rate, delay, jitter, bit error rate, cost of communications, etc., which the network can currently provide at a particular location. Based on the obtained information from several networks, the OTT service provider decides to which network it allocates the user. The network provider takes care about the user allocation to a particular cell, radio resource management and the updates of the network status information exposed to the OTT service provider.
- Cell level network status exposure, where the OTT service provider obtains information about the available data rate, free resource blocks, delay, jitter, bit error rate, cost of the communications, etc., for each cell in the network at a particular location. Based on the received information, the OTT service provider suggests the list of the preferred cells for a particular user. If the network provider agrees, it allocates the user to one or many cells and updates its own REM and fused information, which is exposed to the OTT service provider.

The cell level network status exposure enables the OTT service provider to control user allocation to the particular cell. Based on user estimated daily activities, motion pattern, etc., the service provider may plan the network load, and reserve particular cells for future uses. Furthermore, if the information about the available resource blocks is also exposed, the OTT service provider would have access to radio resource management.

#### 2.1. OTT REM architecture

The functional configuration of the radio environment map with tables and necessary function blocks to perform OTT services shown in figure 1 consists of:

• Cell/network description information: a bandwidth efficiency map for cell or network (which includes information about the bandwidth efficiency available at a particular location), table of served users (contains the IDs of users allocated to a particular cell or network), table of allocated throughput per user, table of allocated bandwidth per user, bandwidth (maximum bandwidth available at a particular cell), throughput is a maximum throughput available at a particular cell.

In addition, the information about the communication cost, delay introduced, delay jitter and other quality of service parameters can also be exposed.

- User description information: user location, user requests (data rate is obligatory, while delay, delay jitter or other quality of service requirements are optional), allocated user requests (the amount of service allocated to the user).
- *Methods for allocation of users to particular networks or cells*: **deterministic method** (allocates users to a particular cell/network according to the priority list), **optimization methods** (optimal allocation of users to the network by minimizing/maximizing at least one objective function). Differential Evolution for Multi-objective Optimization (DEMO) function and its parallel implementation, Asynchronous Master-Slave DEMO is applied in this paper.

## **3.** Differential evolution multi-objective optimization (DEMO) algorithm and asynchronous master-slave demo (AMS-DEMO)

Evolutionary algorithms (EAs) are stochastic optimization algorithms operating on principles similar to those of biological evolution [6]. Given an objective function, EAs search for the optimal arguments by starting with a random set of solutions, which is then tested and stochastically modified. The algorithm runs until a stopping criterion is fulfilled. Differential evaluation (DE) is an evolutionary algorithm for solving single-objective optimization problems defined over continuous domains, while multi-objective optimization searches for a set of optimal solutions according to multiple objectives and compares the results based on Pareto optimality [7] [8]. The outcome of this process is a set of Pareto optimization convergence is tested by calculating a hyper-volume bounded by one generation Pareto optimal solution and a reference point, which has to be worse than the worst possible solution.

Since the objective function is very computationally expensive it is beneficial to parallelize the algorithm for use on multiple processors. We apply an asynchronous master-slave implementation of DEMO algorithm which is particularly suitable for heterogeneous computer architectures.

#### 3.1. Objective functions

The criteria functions have to reflect the operator point of view of the network, i.e. provision of good service to users with the minimal average cost, and the user perspective, obtaining a requested service with the minimal cost. In this respect, the OTT service provider is interested in average QoS parameters, while users are interested in the minimum service parameters. Multi objective functions can be selected to optimize the allocation of users to the networks/cells. We group objective functions into several classes, namely:

#### 1. Maximize quality of service functions:

This set of functions maximizes the QoS parameters in terms of average value in order to satisfy the users on the average, or maximizing the minimum QoS parameters to give some service to all users requesting the service:

• average (mean) QoS calculated for the allocated data rate, the achieved packet error rate (PER) and the average packet delay:

$$\langle QoS_R \rangle = \frac{1}{N_{users}} \sum_{i=1}^{N_{users}} \frac{R_{allocted,i}}{R_{requested,i}}$$
(1)

$$\langle QoS_{PER} \rangle = \frac{1}{N_{users}} \sum_{i=1}^{N_{users}} \frac{1.0 - PER_{achieved,i}}{1.0 - PER_{requested,i}}$$
(2)

$$\langle QoS_D \rangle = \frac{1}{N_{users}} \sum_{i=1}^{N_{users}} \left( \frac{D_{achieved}}{D_{requested}} \right)^{-1}$$
(3)

• minimum QoS calculated for the allocated data rate, the achieved packet error rate (PER) and average packet delay:

$$\min(QoS_R) = \min_{N_{users}} \left( \frac{R_{allocted,i}}{R_{requested,i}} \right)$$
(4)

$$\min(QoS_{PER}) = \min_{N_{users}} \left( \frac{1 - PER_{achieved,i}}{1 - PER_{requested,i}} \right)$$
(5)

$$\min(QoS_D) = \min_{N_{users}} \left( \frac{D_{achieved,i}}{D_{requested,i}} \right)$$
(6)

2. Maximize the number of users to get requested service.

3. Minimize the average cost of providing services:

$$\langle C \rangle = \frac{1}{N_{users}} \sum_{i} Cost_i \tag{7}$$

#### 4. Simulation scenario

The reference simulation scenario consists of three wireless networks, namely (i) macro-cell, (ii) micro-cell and (iii) pico-cell network. The macro-cell network consists of a single cell covering the whole area of interest with the size of 6 km by 6 km. The macro base station is located in the middle of the observation area. The micro-cell network consists of five micro-cells. One micro base station is co-located with the macro-cell base station, while the other four are in the corners of a square with the dimension of 5 km by 5 km. The pico-cell network consists of 13 base stations uniformly spread across the observation area. The locations of the base stations and the bandwidth efficiency maps are depicted in figure 2 a), b) and c). The blue colour denotes areas without coverage, or where bandwidth efficiency is zero. The parameters of macro-cell, micro-cell and pico-cell base stations are shown in Table 1. The free space path loss model is used to calculate path loss, with different path loss parameters, namely 2.6 for macro cells, 3.0 for micro-cells and 4.0 for pico-cells.



Figure 2. Base station locations and bandwidth efficiency map for a) macro, b) micro and c) pico-cell network.

	macro-cell	micro-cell	pico-cell
P <sub>Tx</sub> [dBm]	21.0	15.0	11.0
f [MHz]	2100	2600	2400
BW [MHz]	2	2	2
throughput [Mbits/s]	1	1	1

Table 1. Base macro-cell, micro-cell and pico-cell base station parameters.

#### 5. Simulation results

#### 5.1. Deterministic allocation of users to the wireless network

A deterministic algorithm for user allocation to the network is evaluated first. In order to get impression about the OTT service performance, we build two network priority lists. The first list prioritizes the allocation of users to the macro-cell network, then micro-cell network and at the end to the pico-cell network. The second approach prioritizes the pico-cell network, then micro-cell and finally the macro-cell network. The users are spread uniformly across the area. The required data rates are generated randomly in the range from 0.0 to 0.1 Mbits/s. The values for the maximum throughput of the cells and the maximum throughput of the users are scaled down to shorten the running time of simulations. The average QoS obtained by simulations as a function of the number of users served by

the OTT service provider is shown in figure 3 a) for pico-cell network prioritization, and in figure 3 b) for macro-cell network prioritization. While the number of users is very low, i.e. below 20, all users achieve the required quality of service. However, when the number of users is increased, the macro-cell network prioritization causes the saturation of this network, and when a user is not covered by a micro-cell or pico-cell networks, the required quality of service cannot be provided. This leads to a significant decrease of QoS using macro-cell network prioritization for user allocation to the wireless networks.

In figure 4 the normalized network bandwidth allocation for a) pico-cell network prioritization and b) macro-cell network prioritization is shown. When the pico-cell network prioritization approach is applied, users are allocated to the pico cells first. If they are out of pico cell coverage, the micro cells are applied, and if neither the pico or micro cell can provide sufficient service, the macro cell is used. The results in figure 4 a) also reveal that the bandwidth of the pico-cell network and the micro-cell network should be slightly increased to achieve similar rate of normalized bandwidth increase with the number of users. This will result in more balanced usage of all networks, which should be the goal of user allocation to different networks.

Results plotted in figure 4 b) reveal that the maximum load of the macro-cell network is achieved at a relatively low number of users, while other networks remain completely unloaded. Furthermore, due to the low coverage of pico-cell network, the capacity of the pico-cell network remains unexploited resulting in a huge drop of the average QoS.

Similar conclusions can be drawn from figure 5 which reveals the maximum throughput at any network is not reached. Less than 20% of the available throughput is achieved for a high number of users. This leads to the conclusion that the cell bandwidth limits the number of users allocated to the particular network. In this respect an increase of the cell bandwidth can be a solution to use the networks more efficiently.







Figure 4. Normalized network bandwidth allocation a) pico-cell network prioritization and b) macro-cell network prioritization



Figure 5. Normalized network throughput allocation a) pico-cell network prioritization and b) macro-cell network prioritization

#### 5.2. AMS-DEMO optimized allocation of users to the networks

The bounds of simple deterministic user allocation to different service networks are obtained in the previous subsections. In order to obtain significant improvement of the average quality of service we use AMS-DEMO optimization algorithm for user optimal allocation. We assume 400 randomly placed users in an area. The user throughput is a random parameter but it is limited to 0.1 Mbits/s. Two objective functions are used, namely the average quality of service throughput and the average cost. The simulation results are shown in Table 2. The optimization of the service allocation to different networks outperforms the deterministic approach.

	macro-cell prioritized network	pico-cell prioritized network	DEMO
Average QoS	0.6775	0.8275	0.89

Table 2. Base macro-ce	ll, micro-cell and	pico-cell base station	parameters.
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However, the computation time for DE optimization exceeds the time expected for on-line OTT services optimization. A significant reduction of the computation time is achieved by using parallelization on a cluster of computers.

Our experimental setup is a cluster consisting of 17 dual-processor nodes (each node being a personal computer). Each node contains two AMD Opteron-244 processors with 1024 MB of RAM, a hard disk drive, six 1000 MBit/s Full Duplex Ethernet ports and an independent installation of the Fedora Core 2 operating system. Nodes are interconnected through an Ethernet switch. During the experiment only background system processes are running on the nodes, leaving nearly all capabilities free for use by the algorithm.

Table 3. AMS-DEMO speedups [7] [8].

Number of	Speed up	
processors		
1	1.000	
2	1.997	
4	3.982	
8	7.922	
16	15.68	
32	30.74	

The speedups achieved by the use of multiple processors are shown in Table 3. The speedup is nearly linear with the number of processors, with a slight degradation due to the increased communication needed to collect information at one processor.

#### 6. Conclusion

Over-the-top service allocation to different network service providers based on the exposure of the network service provider QoS and interference maps is proposed. A deterministic allocation of users to the networks and an optimized allocation based on multi-objective evolutionary algorithm is studied. The pico-cell network prioritization approach significantly outperforms the macro-cell network prioritization approach in particular in highly loaded networks. The multi-objective evolutionary approach is tested only at highly loaded wireless networks, where a noticeable improvement in quality of service is observed.

The approaches are studied on a reference wireless network configuration only. The next step is to extend the study to real wireless networks and real propagation environments, with several wireless network providers offering 5G, LTE and WiFi wireless networks.

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