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Vertical Handover and Load Balancing Decision Algorithms for Heterogeneous Cellular-WLAN Networks

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Abstract: Multi-access and heterogeneous wireless communications are one of the solutions for providing generalized mobility and improved user experience. This paper proposes Vertical Handover (VHO) and Load Balancing (LB) decision algorithms for heterogeneous network architectures which integrate cellular networks and Wireless Local Area Networks (WLANs). The cellular-WLAN VHO and LB decisions are taken based on parameters which characterize both the coverage and traffic load. Computer simulations performed in realistic scenarios show that the proposed VHO algorithm ensures better performance compared to "classical" ones and that the LB mechanism can significantly offload the congested cellular networks when WLAN connectivity is available.

Keywords: ubiquitous connectivity, vertical handover, heterogeneous networks, decision algorithm, network state information, load balancing.

1. Introduction

An important characteristic of Next Generation Networks will be the integration of heterogeneous wireless access technologies, which will lead to increased overall system efficiency and improved user experience. Several issues concerning service continuity and resource management are still unsolved and require further research.

The authors of [1] present a survey of existing technologies that support multimedia communications in a heterogeneous wireless network and the main requirements and solutions for mobility management are discussed. In [2] the

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authors review the emerging protocols and architectures aiming to support intersystem handovers and present an optimized handover framework built around the functionality introduced by the IEEE 802.21 standard.

In [3] a new architecture and a new network selection scheme that takes into account the resource usage and the user's preferences are proposed. The solution presented ensures the selection of the most suitable network for each flow while taking into account the QoS requirements of the services. In [4] the authors propose another solution for handover management which answers the user's requirements and ensures service continuity in 3G-WLAN, 3G-WMAN and WMAN-WLAN networks.

In [5] a novel MIHF (Media Independent Handover Function) based seamless inter-RAT (Radio Access Technology) handover algorithm is proposed for UMTS and WiMAX networks. This solution uses cross-layer techniques for providing lossless handover while keeping acceptable delays. Improvement possibilities of the inter-system handover mechanisms in the 3GPP Evolved Packet Core environment are studied in [6] while other VHO optimization mechanisms for 4G networks are proposed in [7].

Resource sharing and management in heterogeneous wireless networks involve complex operations with contradictory requirements, but in the same time can offer more efficient usage of the limited frequency bands. Many papers studied various aspects related to cooperation in heterogeneous networks. In [8] the authors propose a Cooperative Radio Resource Management (CRRM) solution between heterogeneous air-interfaces. Strategies for CRRM in coexisting WiMAX and HSDPA networks are developed in [9]. Scenarios with or without inter-system VHO were considered, showing that RRM combined with VHO maximizes the throughput.

In [10] the authors investigate the issue of parallel transmissions over multiple RATs, focusing their attention on the QoS perceived by the final users. A simple but effective CRRM algorithm is proposed and evaluated in 802.11a-UMTS and 802.16e systems scenario. In [11] it is proved that load balancing is a significant method to achieve resource sharing over heterogeneous wireless networks and to provide better services.

The concept of soft load balancing mechanisms was presented in [12], while in [13] the authors propose a Flow Diversion-based Vertical Handoff Algorithm relying on soft load balancing. The authors adopt a Fuzzy Neural Network to determine the optimal flow-dividing ratio in order to balance the network load.

Other interesting cooperation solutions over heterogeneous networks proposed in the technical literature are the following: in [14] the authors propose a Multi-Radio Cooperative Automatic Retransmission Request scheme, which combines long-range and short-range communications for retransmission of lost packets; in [15] the authors illustrate a way of implementing cooperation mechanisms at IP Multimedia Subsystem level between networks that share the same IP core; in [16] the authors present a hierarchical architecture for load balancing based on the idea of grid in computer networks.

This paper proposes an improved VHO decision algorithm and a LB algorithm for 3G/4G – WLAN heterogeneous network architectures which offer support for advanced MIH mechanisms. The structure of the paper is the following: Section 2 introduces the system model, Section 3 presents the proposed VHO and LB algorithms, while Section 4 presents the evaluation methodology of the proposed algorithms. Section 5 presents the results obtained by computer simulations using the Network State Information (NSI) acquired by field measurements and Section 6 presents the main conclusions the paper.

2. System model

The system model considered, presented in *Fig. 1*, can be described as follows: it is given a heterogeneous network composed of 3G/4G cellular networks, providing large coverage, and public WLAN/WiFi networks having the role to offload the traffic passing through the 3G/4G networks. The coupling between the heterogeneous networks is implemented by specially designed gateways, the Service Continuity Gateways (SCG). The coupling infrastructure includes also a Central Database (CD) which stores link state and traffic related information for each wireless network. A specially designed server, the Connectivity Support Server (CSS), controls the access of the users to CD.

Two categories of users are considered:

- Individual users with mobile terminals (MT) equipped with one cellular and one WiFi interface. The MT runs the algorithms which implement the VHO between cellular and WiFi networks, aiming to maintain the service continuity.
- Mobile Routers (MR) installed in transportation vehicles and equipped with one or several cellular and WiFi interfaces. These MRs run the algorithms which can implement not only VHO between the cellular and WiFi networks but also load balancing operations which allow the joint usage of the transmission resources available in several networks. In an urban environment the transportation vehicles have low speed and frequent stops which makes possible the usage of WLANs for providing Internet access to the passengers.

It is supposed also that the mobile terminals and the MRs are equipped with GPS receivers, being capable to establish their geographical position and speed.

This paper proposes VHO and LB decision algorithms which allow selecting the best WLANs for transmission respectively distributing the data flows of the users on several WLANs, when the speed of the mobile terminal is low. The

NSI and traffic related information necessary for selecting the target networks for VHO and/or LB can be acquired from the CD of the coupling infrastructure. The algorithms implementing the routing in the heterogeneous network and the access to the CD are beyond the scope of this paper. See for details [17] [18].

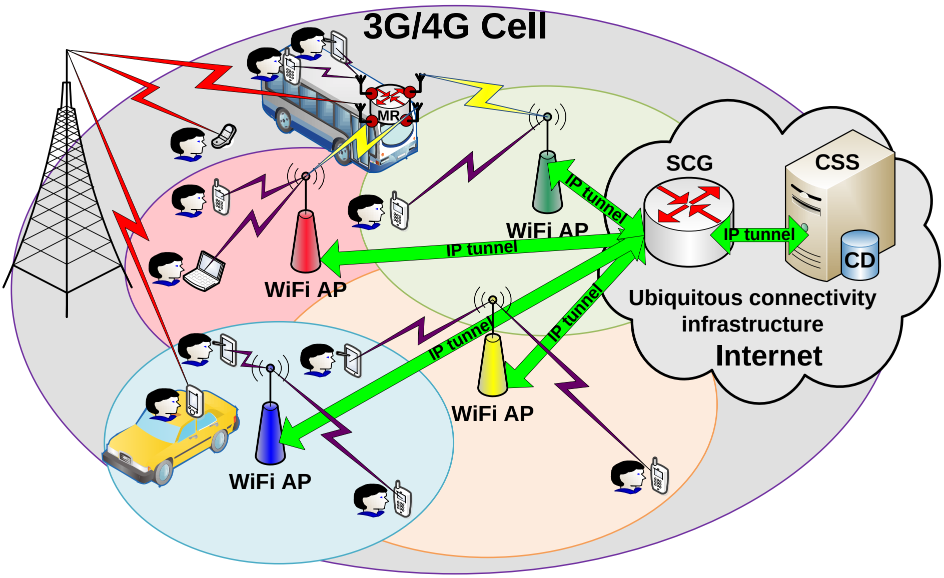

Figure 1: The system model of the considered heterogeneous network.

3. Vertical handover and load balancing algorithm for cellular-WLAN heterogeneous networks

The proposed algorithm which performs both cellular-WLAN and WLAN-WLAN VHO processes is based on the flowchart presented in *Fig. 2*. The algorithm is intended for individual users who do not perform load balancing between the cellular and WiFi networks. The users travelling with vehicular speed are connected to cellular networks while pedestrian users try to connect, if possible, to WLANs (see *Fig. 1*), the cost of the Mbyte transmitted in WLANs being significantly lower compared to 3G/4G networks.

The selection of the target WLAN is performed, by the user terminal, based on the Received Signal Strength (RSS) and Available Transmission Rate (ATR) parameters of the wireless link. The cost of the transmission taking place in the WLAN also can be considered.

The estimated ATR of the wireless link can be computed as:

$$ATR_{est} = f(RSS) \cdot (1 - BLER) \cdot (1 - ChBPF) \quad (1)$$

where $f(\text{RSS})$ gives the average bit rate of the WiFi connection as a function of the RSS; ChBPF – Channel Busy Period Fraction represents the fraction of the active time when the WiFi channel is used for transmission.

The WiFi link's Block Error Rate (BLER) can be computed based on the evaluation of the Signal to Interference and Noise Ratio (SINR) of the WiFi link or by counting the ACK/NACK messages received by the MAC layer.

The parameters used in target network selection have different measurement units, so normalization is a necessary step. The used max-min normalization is described by the following relation:

$$v_{ij} = (\mathrm{x}_{ij} - \min_i(\mathrm{x}_{ij})) / (\max_i(\mathrm{x}_{ij}) - \min_i(\mathrm{x}_{ij})) \quad (2)$$

where x_{ij} is the value of the j-th parameter in the i-th network and v_{ij} is the normalized value of x_{ij}.

In order to compare the different networks a utility function is defined:

$$C_i = \sum_{j=1}^{M} w_j v_{ij} \quad (3)$$

where M is the number of parameters and w_j is the weight of parameter j.

The VHO target network is the one with the highest value of the utility function. In order to compute the weights w_j a pair-wise comparison of all parameters should be performed using a pairwise comparison matrix **B**, with dimension MxM, whose elements are the b_{ij} comparisons between the i-th and j-th parameter. In order to build this matrix it is needed to indicate how many times more important or dominant one element is over another [19].

Finally the weight vector **w** can be computed by solving the equation [20]:

$$(\mathbf{B} - \lambda\mathbf{I}) \cdot \mathbf{w} = 0 \quad (4)$$

where λ is the eigenvalue of **B** and **I** is the identity matrix. The weight vector $\mathbf{w} = [w_1, ..., w_M]^T$ is the eigenvector of **B** corresponding to eigenvalue λ_{max}.

The LB algorithm was designed for Mobile Routers equipped with 3G/4G interfaces and several WiFi interfaces. This algorithm is an extension of the VHO algorithm presented in *Fig. 2*, more exactly the 3G-WLAN and WLAN-WLAN VHO process (see the shaded box in *Fig. 2*) is replaced by a LB process, performed according to the flowchart presented in *Fig. 3*. The LB process starts when the speed of the vehicle drops below an imposed limit (close to pedestrian speed) and it distributes some of the flows passing through the 3G/4G link (or links) on several WiFi links. The selection of the target WLANs involved in the LB process is performed based on the utility functions and if significant changes of the RSS or of the ATR parameter are detected on any WiFi link, then the LB process is restarted and all flows are reassigned.

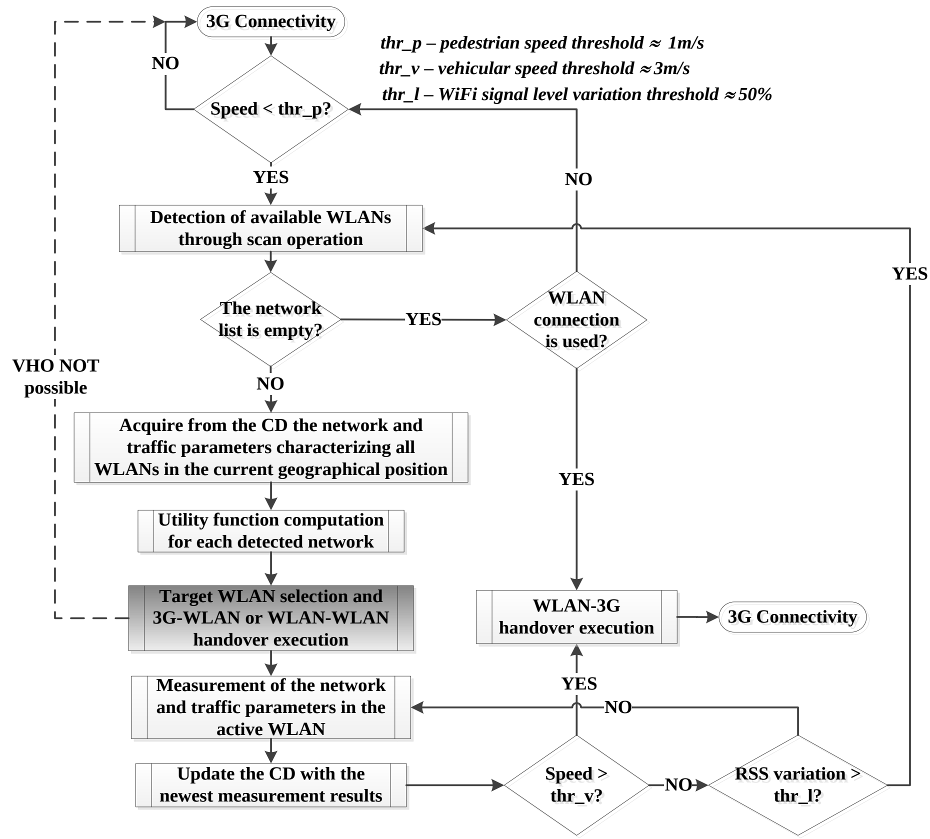

Figure 2: The proposed cellular-WLAN and WLAN-WLAN VHO algorithm.

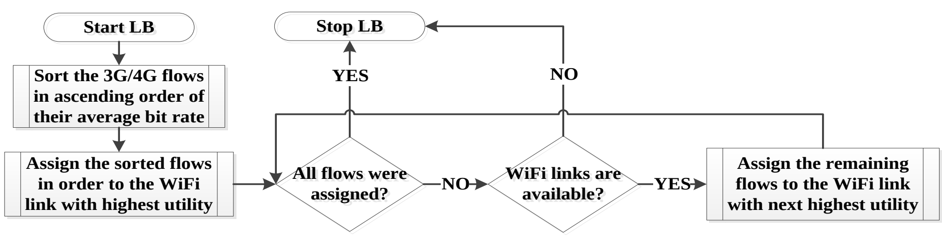

Figure 3: The proposed LB algorithm for cellular-WLAN heterogeneous networks.

4. The evaluation methodology and the test scenarios

In order to evaluate the performance of the proposed VHO and LB mechanisms the following methodology was used: using a real test site the RSS and the ATR parameters of the WLANs composing the heterogeneous network were acquired and the data obtained were fed into a system level simulator, developed in the UCONNECT FP7 project. The simulation performed replicates a real scenario in which a MT or a MR is moving in the coverage area of several WLANs and VHO and LB operations are taking place according to the proposed algorithms. The WLAN test network, located in a university campus, includes 5 WiFi (802.11g) Access Points (APs), and it is presented in *Fig. 4*. The RSS variations experienced by the mobile terminal during its journey are depicted also in *Fig. 4*. By assigning to each WiFi AP non or partially overlapping channels the estimated BLER parameter was kept smaller than 0.1. The background traffic (generated using the *Iperf* tool), for each of the five APs, is presented in *Table 1* for two scenarios. The ChBPF parameter was measured for each AP in different ranges of the RSS parameter (see *Fig. 4*).

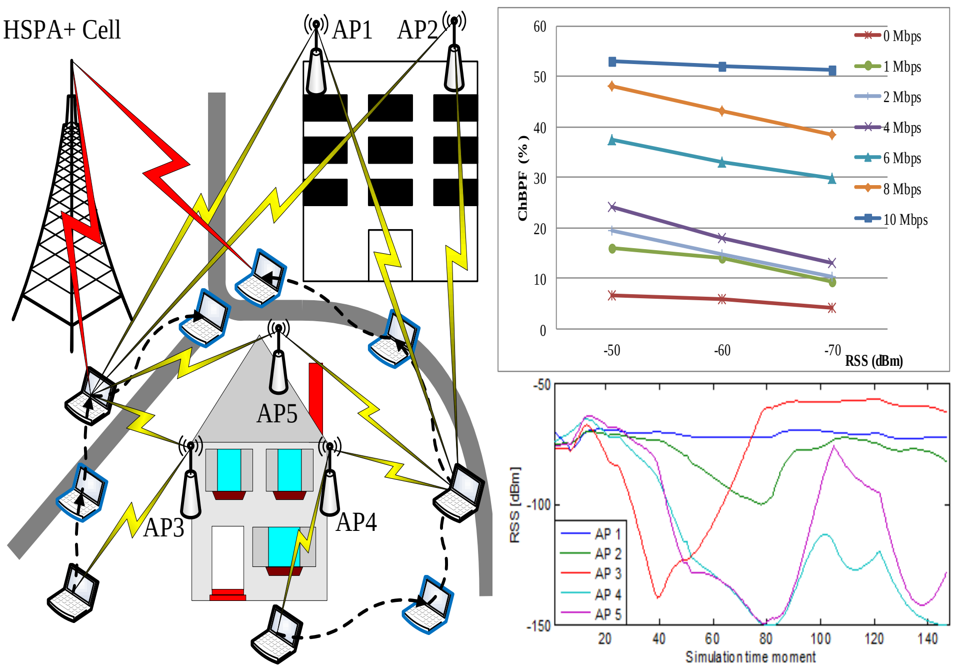

Figure 4: 3G-WLAN and WLAN-WLAN VHO test scenario. ChBPF versus RSS for different traffic values. RSS variation along the route of the monitoring terminal.

5. Simulation results

One of the targets of this study was to evaluate the performance of various VHO target network selection mechanisms. We considered, besides the RSS and ATR based decisions, the decision process based on the utility function, which was computed for each AP using relation (3). The weights of the parameters considered were assigned empirically according to *Table 2*.

Table 1: Background traffic passing through APs and the cost of the transmitted MByte.

AP	Scenario 1	Scenario 2	Cost of MByte
AP1	6Mbps	1Mbps	0.1
AP2	8Mbps	2Mbps	0.2
AP3	10Mbps	10Mbps	0.15
AP4	1Mbps	8Mbps	0.25
AP5	0Mbps	0Mbps	0.3

Table 2: Weights considered in the different test scenarios.

Weighting method index	Algorithm	Weights		
		ATR	RSS	Cost
1	ATR based	1	0	0
	RSS based	0	1	0
	ATR+RSS based	0.4	0.6	0
	ATR+RSS+Cost based	0.3	0.6	0.1
2	ATR based	1	0	0
	RSS based	0	1	0
	ATR+RSS based	0.5	0.5	0
	ATR+RSS+Cost based	0.33	0.33	0.33
3	ATR based	1	0	0
	RSS based	0	1	0
	ATR+RSS based	0.6	0.4	0
	ATR+RSS+Cost based	0.6	0.3	0.1
4	ATR based	1	0	0
	RSS based	0	1	0
	ATR+RSS based	0.55	0.45	0
	ATR+RSS+Cost based	0.45	0.35	0.2

In *Fig. 5* and *Fig. 6* the achievable average transfer rate is presented for Scenario 1 and 2 (see *Table 1*) for the decision and weighting methods considered. These results show that the ATR based decision offers the best performance and the RSS based decision the worst one, but the measurement precision of ATR is lower, thus the decision process cannot consider only the ATR parameter. One solution is to select the VHO target network based on the utility function. The combined usage of the RSS and ATR parameters reduces the influence of the ATR measurement imprecision, while keeping the average achievable tranfer rate approximately the same. One can also notice that the decision which takes into consideration the cost of the networks has lower performance than the algorithms which neglect the cost parameter, because in this case the network with the highest achievable rate is not always selected.

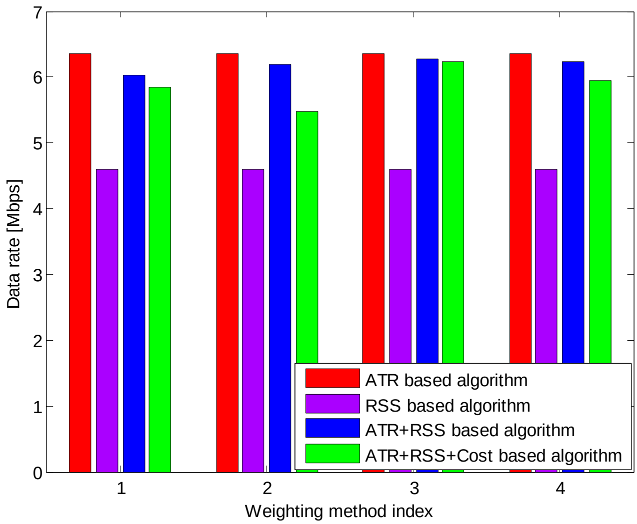

Figure 5: Average achievable transfer rate obtained in the case of Scenario 1.

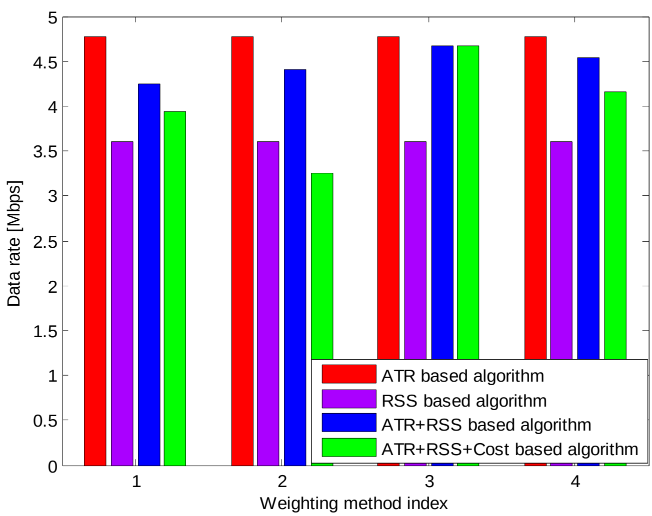

Figure 6: Average achievable transfer rate obtained in the case of Scenario 2.

Another target of this study was to evaluate how much a 3G+ link can be offloaded when using several WiFi links and the proposed LB algorithm. This test scenario involves a MR equipped with a 3G+ interface and with several WiFi 802.11g interfaces. The measured average downlink ATR of the 3G+ link was ≈ 11Mbps (see *Fig. 7*). The MR is moving on a path covered by the 5 WiFi APs presented in *Fig. 4* and having the background traffic given in *Table 1* (Scenario 1). The test flows are represented by 10 video streaming flows with 800kbps average rate and 10 web radio flows with 128kbps average rate. All these test flows can be carried by the HSPA+ interface, with an average usage ratio of ≈ 90% (usage ratio of the available capacity, i.e. the ATR). The selection of the target WLANs is performed using the RSS and ATR parameters and equal weights, i.e. weighting method 2 in *Table 2*.

In the considered scenarios a single WiFi can completely offload the 3G+ link if all the available transmission resources of the WLANs can be used by the MR. However, in a real situation the WLAN resources allocated to a user/MR are limited in order to ensure fairness between the users. *Fig. 8* gives the average usage of the 3G+ link if 2, 3 respectively 4 WiFi interfaces are used and the transmission rate is limited to 6% respectively to 3% of the 802.11g WiFi link rate (i.e. 54Mbps).

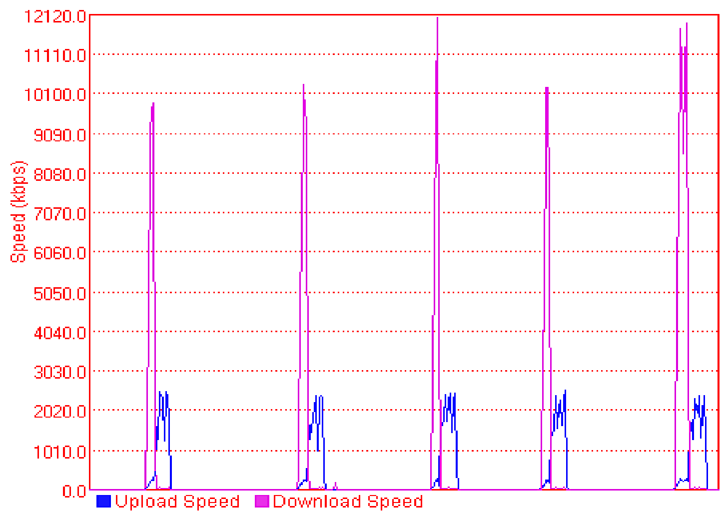

Figure 7: 3G+ link ATR parameter measurement.

The results presented in *Fig. 8* show that a LB process over 2 – 3 WiFi 802.11g networks, having “normal” background traffic can offload significantly the 3G+ link of a MR, while reducing the network usage cost.

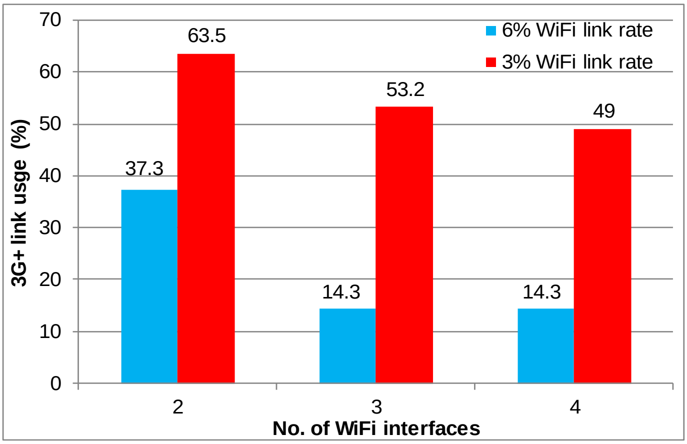

Figure 8: 3G+ link usage in the considered LB scenarios.

6. Conclusion

The paper proposes a VHO and a LB decision algorithm for cellular-WLAN heterogeneous networks. The proposed decision algorithms act based on the NSI and traffic information stored in the central database of the network architecture. Both algorithms aim at offloading the cellular networks by using, when possible, public WLANs. The LB algorithm represents an extension of the VHO algorithm and it is intended for mobile routers. Computer simulations performed in a scenario involving a 3G+ network, 5 WiFi APs and real NSI and traffic information show that the proposed VHO decision algorithm performs better compared to "classical" ones. The simulations performed highlight also the potential of the LB algorithm in offloading the 3G/4G links if several WLANs are available and the MR is equipped with 2 – 3 WiFi interfaces.

Acknowledgements

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