URAN: **U**tility-based **R**eputation-oriented **A**ccess **N**etwork Selection Strategy for HetNets

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***Abstract* — The small cell deployment is seen as a promising solution for the network operators to help them cope with the increasing number of mobile broadband data subscribers and their bandwidth-intensive application demands. The result is a HetNet, heterogeneous network environment with a combination of macro-cells and small cells to spread the traffic load, increase the bitrates and maintain the service quality. In this context, network selection mechanisms will be required to keep the mobile users always best experienced. In this paper, we propose a theoretical framework URAN, for combining utility-based network selection mechanism with reputation-based systems. URAN makes use of the user preferences and service requirements to define a network reputation factor which reflects the user satisfaction on the network's previous service guarantee to the mobile user.**

Keywords—network selection, reputation-based systems, HetNets

I. INTRODUCTION

The mass-market adoption of the high-end mobile devices as well as the increasing amount of video traffic has led the mobile operators to adopt various solutions to help them cope with this explosion of mobile broadband data traffic while ensuring Quality of Service (QoS) to the mobile users. Deploying small-cell base stations within the existing macro-cellular networks, especially in the 3GPP Release-10 [1], is seen as a promising solution to increase capacity and improve the network performance at low cost by offloading the traffic from the large macro-cells. The small cells environment is also referred to as Heterogeneous Networks (HetNets) and is seen as part of the existing and next generation network deployments. In this context, the Always Best Experience vision emphasizes the scenario of a mobile user seamlessly roaming in a HetNet environment as seen in Fig. 1. Due to the heterogeneity of the selection criteria, such as: the applications requirements (e.g., voice, video, data, etc.); different device types (e.g., smartphones, netbooks, laptops, etc.) with various capabilities; multiple overlapping network technologies (e.g., Wireless Local Area Networks (WLAN), Long Term Evolution (LTE)) and different user preferences, the mobile users will be facing a complex decision when selecting the best value network to connect to.

According to Cisco, by 2019, 97% of the total mobile data traffic will be generated by the mobile-connected devices and by 2016, more than half of this mobile traffic will be offloaded from the cellular network to Wi-Fi and femtocells [2]. In this way, by transferring some of the traffic from the core cellular network to Wi-Fi or femtocells at peak times or key locations (e.g., home, office, public HotSpots, etc.) the mobile operators can accommodate more mobile users and the users can avail of a wider service offering.

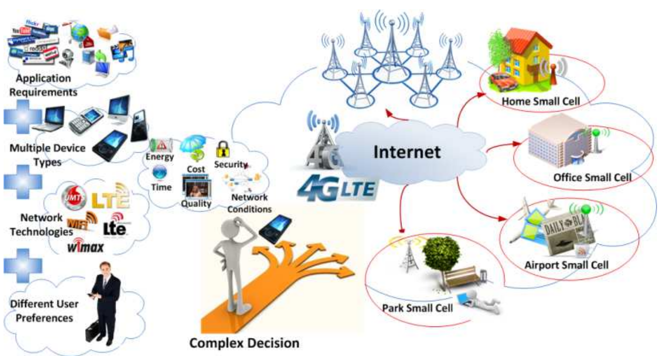

Fig. 1. HetNet Environment – Example Scenario.

At the mobile user side, the mobile devices have become affordable and powerful with improved CPU, graphics and display contributing to the increase in user demands. Due to the growth of the video content usage, such as IPTV, video on demand (VoD), 3DTV, which is estimated to reach 72% of the world's mobile data traffic by 2019 [2], ensuring a seamless experience at high quality levels to the end-user has become a challenge. Furthermore, it is known that video-based applications have strict QoS requirements representing the most power-hungry applications. In this context, one of the main impediments of progress is the battery lifetime of the mobile device as the battery life has not evolved in-line with the processor and memory advances, becoming a limiting factor.

In this work, we propose **URAN**, an **U**tility-based **R**eputation-oriented **A**ccess **N**etwork selection mechanism which combines the utility-based network selection mechanism with the reputation-based systems. The focus is on the user-network interaction, where we define a network reputation factor obtained as a result of the user's previous experience with the network. The network reputation factor is then integrated in the network selection decision in order to sustain cooperation between the user and the network.

II. RELATED WORKS

Various network selection solutions using different techniques have been proposed in the research literature in order to strengthen the Always Best Connected vision. One of the widely used techniques is the applicability of utility functions to describe the users' perception of performance and satisfaction. However, because of the traffic heterogeneity a precise definition of a utility function becomes very complicated. The most popular utility function shapes are defined by Rakocevic et al. in [3] for three broad classes, such as brittle traffic, stream traffic and elastic traffic. However, all the existing approaches have a common goal of optimizing the network performance by maximizing the utility function.

In terms of reputation systems, these have been studied and deployed in the wireless environment [4] with a specific application to the mobile ad-hoc networks, wireless mesh networks, and peer-to-peer scenarios when trying to solve cooperation and decision making problems. Zekri et al. in [5] proposed a vertical handover management solution combining the use of reputation as a Quality of Experience (QoE) indicator for fast decision-making. This solution collects individual user experience on QoS and by users expressing their past experiences, the system aggregates the individual score and computes a reputation value for Wi-Fi, WiMAX and UMTS networks. The performance results show that this solution provides better handover latency and throughput than other solutions. Whereas in [6], the authors proposed an enhanced IEEE 802.21 Media Independent Handover (MIH) [7] based framework that integrates a Vertical Handover Management Engine (VHME) for vertical handover decision-making based on networks reputation. The authors make use of a large set of parameters that map the QoS and QoE to a network reputation value.

Giacomini et al. in [8][9] proposed a reputation based vertical handover decision rating system by making use of the grey model first order one variable (GM (1, 1)). The proposed solution provides a quick and efficient prediction of the reputation score for a target network in the handover decision making progress. The QoS parameters like Bit Error Rate (BER), delay, jitter and bandwidth are used to calculate the reputation value for UMTS, WiMAX and WLAN networks. The proposed solution was evaluated through simulations and the results show that the reputation-based system can provide the mobile node with advance time to make a successful handover and thus experience an overall higher QoS.

Trestian et al. in [10] propose a reputation-based network selection mechanism using game theory. The user-network interaction is modeled as a repeated cooperative game and the reputation of the network is computed based on the user's payoff. The proposed solution is based on individual user experience and the mechanism is integrated into an extended version of the IEEE 802.21 model.

Unlike previous works, this paper proposes to combine the utility-based network selection mechanism proposed for real-time applications [11] with the reputation-based systems in order to select the best value network for the mobile user.

III. URAN System Architecture

A. *URAN Proposed Architecture Stack*

The proposed utility-based reputation-oriented access network selection mechanism, URAN, aims at building a reputation-based system between the users and the networks they are visiting. As illustrated in Fig. 2, URAN framework block-level architecture is distributed and consists of a server side component, referred to as URAN MIH Information Server, which integrates the Network Ranking Algorithm and a

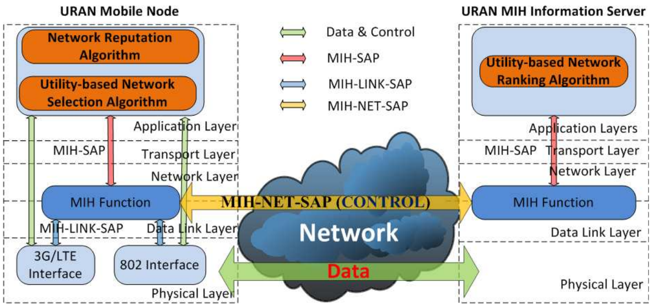

Fig. 2. URAN System Architecture

client side component referred to as URAN Mobile Node, consisting of the Network Reputation Algorithm and the Utility-based Network Selection Algorithm. URAN is built on top of the IEEE 802.21 MIH standard, thus both system components are MIH-enabled entities [12].

The MIH framework defines a cross-layer MIH function (MIHF) as a logical component between the network layer and the link layer [7]. Each of the MIH-enabled entities contain a cross-layer MIHF. This function provides Service Abstraction Points (SAP) acting as an abstract interface between a service provider and a user entity. User entities at higher layers employ the MIH-SAP to control or to monitor the link-layer entity and the MIHF uses the MIH-LINK-SAP as an interface together with the link layer to translate the information received from the MIH-SAP. The remote MIHF entities use the MIH-NET-SAP to exchange the information with the MIHF [13].

B. *URAN Functional Principle*

The URAN functionality considers a scenario inspired from the daily life of a mobile user, who while going from home to office, wants to access multimedia services (e.g., watching the news, music video clips, etc.) via a number of available wireless networks, as seen in Fig. 3. As the mobile user is taking the same path every day will be crossing the same networks, making it possible to build a timeline/history of the user interaction with different networks. In this context, URAN, a reputation-oriented network selection mechanism is proposed. The idea behind URAN is that each user can have different experiences with different network operators, depending on the user preferences and the service requirements. As a result of this user-network interaction, a reputation factor can be computed for that particular network. For example, if the user was satisfied with the offered services, the network will receive a higher reputation value reflecting the user satisfaction.

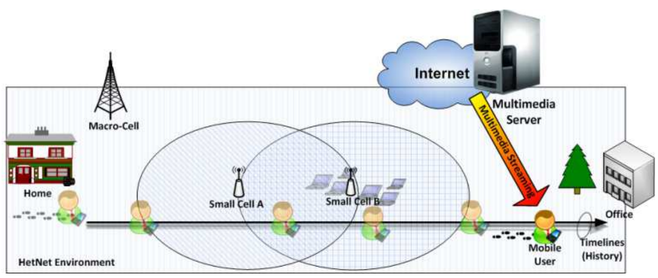

Fig. 3. HetNet Environment – Example Scenario of a Mobile User Daily Routine

The proposed URAN solution combines the utility theory with the reputation theory to build a reputation-based system between the users and networks. Within the HetNet environment, having a pool of available wireless networks and their characteristics, the URAN based mobile node will send a ranking request to the URAN MIH Information Server. The network ranking algorithm located at the URAN server side will compute a network ranking list based on three criteria, such as: energy consumption of the mobile device when running real-time applications, the monetary cost of each network, and the estimated quality of the multimedia stream. The network ranking algorithm makes use of utility functions [11] to compute an overall ranking score for each network. A ranked list of networks along with their expected utility scores is then sent to the URAN mobile node. At the end user side, in the first instance the utility-based network selection mechanism will select the best value network from the ranked list received from the server. After the user connects to the target network, a user-network interaction session starts where the service quality is monitored. At the end of every user-network interaction, a network reputation factor is computed based on the experienced utilities. This network reputation factor will impact the score of each network next time the network selection takes place.

C. Proposed Utility-based Network Ranking Function

The use of utility function together with the Multiplicative Exponential Weighted (MEW) method in the decision making mechanisms has been shown to be useful in [14]. A generic model of the network ranking function is given in eq. (1):

$$U_i = u_{e_i}^{w_e} \cdot u_{q_i}^{w_q} \cdot u_{c_i}^{w_c} \qquad (1)$$

where i represents the candidate network, U_i is the overall utility for network ranking and u_e, u_q, u_c are the utility functions defined for energy, quality and monetary cost for network i, w_e, w_q, w_c are the weights for the three considered criteria: energy, quality and monetary cost, respectively and $w_e + w_q + w_c = 1$. The network ranking function is computed for each of the candidate networks and a ranked list is send to the URAN mobile node. The utility functions used were previously proved to be efficient in a wireless multimedia heterogeneous environment [15].

a) Energy Utility – u_e

The estimated energy consumption for a real-time application is computed using eq. (2) as defined in [16]:

$$E = t(r_t + Th_{req} r_d) \qquad (2)$$

where t represents the transaction time (s) which can be estimated from the duration of the video stream, r_t is the mobile device's energy consumption per unit of time (W), Th_{req} is the required throughput (kbps), r_d is energy consumption rate for data/received stream (J/Kbyte), and E is the total energy consumed (J). The parameters r_t and r_d can be determined by running different measurements for various amounts of data and defining an energy consumption pattern for each interface [15]. Based on the estimated energy consumption E, the utility for the energy criteria u_e is computed using Eq. (3) [15]:

$$u_e(E) = \begin{cases} 1 & , \quad E < E_{\min} \\ \dfrac{E_{\max} - E}{E_{\max} - E_{\min}} & , \quad E_{\min} <= E < E_{\max} \\ 0 & , \quad otherwise \end{cases} \qquad (3)$$

where E is the energy consumption for the current network (Joule), and E_{min} and E_{max} are the minimum and maximum energy consumptions needed for the current video streaming application to run until completion, being calculated using eq. (2) for Th_{min} and Th_{max} respectively.

b) Quality Utility – u_q

A zone-based quality sigmoid utility function is used to map the received bandwidth to user satisfaction [17]. The mathematical formulation of the utility function that maps the quality of the multimedia application is given in eq. (4):

$$u_q(Th) = \begin{cases} 0 & , \quad Th < Th_{\min} \\ 1 - e^{\frac{-\alpha * Th^2}{\beta + Th}} & , \quad Th_{\min} <= Th < Th_{\max} \\ 1 & , \quad otherwise \end{cases} \qquad (4)$$

where α and β are two positive parameters which determine the shape of the utility function and Th is the predicted average throughput for each of the candidate networks. The minimum throughput (Th_{min}) is a threshold to maintain the multimedia service at a minimum acceptable quality level, values below this threshold result in unacceptable quality levels. Whereas values above the maximum throughput (Th_{max}) threshold will not add any noticeable improvements in the user perceived quality. The values for α and β used in this study are 5.72 and 2.66 [17], respectively

c) Cost Utility - u_c

The cost utility is important as there is a natural human tendency to reduce the monetary cost. The mathematical definition of the cost utility is given in eq. (5) [15].

$$u_c(C) = \begin{cases} 1 & , \quad C < C_{\min} \\ \dfrac{C_{\max} - C}{C_{\max} - C_{\min}} & , \quad C_{\min} <= C < C_{\max} \\ 0 & , \quad otherwise \end{cases} \qquad (5)$$

where C is the monetary cost for the current network, C_{min} and C_{max} are the minimum and the maximum costs that the user is willing to pay.

D. Proposed Utility-based Reputation Function

The network ranking function provides a list of ranked networks based on the overall scores obtained using the utility function defined in eq. (1). These scores are the expected utilities that the users will receive once connected to a particular network. However, during the connectivity session with the target network, the network conditions might change thus the utility received by the user might be different from the initial expected utility. In order to reflect this in the network selection process, at the end of every user-network interaction, a network reputation factor is computed. Thus, a new utility-based reputation function is given in eq. (6):

$$U_{Ri} = \gamma_i U_i \qquad (6)$$

where: U_{Ri} is the utility-based reputation-oriented function for candidate network i, γ_i is the reputation factor for network i, and U_i is the network ranking function for network i. The network reputation factor γ_i, represents the degradation observed by the user in the past interactions with network *i*, the higher the value of the network reputation factor the smaller the observed degradation. The network reputation factor is computed for each network and then used in the network selection process as defined in eq. (6). The network with the highest score is selected as the target network.

- *Network Reputation Factor* - γ_i

In order to keep track of the past experience with a particular network and strengthen the cooperation between users and networks, a reputation factor γ is defined. γ is computed based on the user's past interactions with the network. It is assumed that at the first contact between the user and the network, γ =1, meaning that the network reputation factor will not have any impact on the selection as there is no history between the user and the network. In order to prevent the case in which an operator, after getting high reputation in the past, can change the attitude by providing QoS degradation in the recent times, the user-network interactions are weighted. For example, people tend to remember the recent experiences more than the past ones, for this reason the present interactions will have a higher weight which will reduce smoothly as the interaction becomes older [10]. Thus, the network reputation factor, γ_i for a network *i*, is defined based on the age of the user-network interaction as given in eq. (7).

$$\gamma_i = {\sum_j^n w_{ji} U_{E_{ji}}}/{n} \tag{7}$$

where w_{ji} represents the weighted assigned to interaction *j* with network *i*, and U_{Eji} is the experienced utility at the end of interaction *j* with the network *i*. U_{Eji} is computed with eq. (1) by using the actual values experienced by the user at the end of each user-network interaction.

The weight w_{ji} is computed using the eq. (8) defined below:

$$w_{ji} = {\left(e^{(j-n)/\rho} - 1\right)}/{\left(e^{-n/\rho} - 1\right)} \tag{8}$$

where *j* is the interaction with the network *i*, *n* is the total number of interactions, ρ is the importance tolerance of the weight. The values of w_{ji} are within [0,1] interval, with 1 representing high importance and 0 representing low importance, as the importance of the user-network interaction is reduced with time passing.

IV. Numerical Results and Discussions

In this section, the simulation scenario will be described and the numerical results analyzed.

A. *Scenario Description*

The proposed algorithm was analyzed using a scenario from a typical day in a business professional life, who wants to be always best connected to the Internet in order to access multimedia content from a multimedia server while on his regular commute to work as illustrated in Fig. 4. As the mobile user is travelling every day from his Home (point A) to his Office (point F), he is passing across several available wireless networks (e.g., UMTS and WLAN) which may belong to the same, or to different network operators. First the user is connected to the UMTS network which has the widest range (point A). As he passes through the areas with a number of other available networks (e.g., WLAN A and WLAN B), a network selection decision has to be made at the following points: B, C, D, and E as marked in Fig. 4. Because the mobile user is taking the same path every day, it can be considered that he has a history of interactions with different wireless networks he accessed on his way. The outcome of each user-network interaction is given by a reputation factor for each visited network. This enables a reputation-based network selection mechanism to be built (point F).

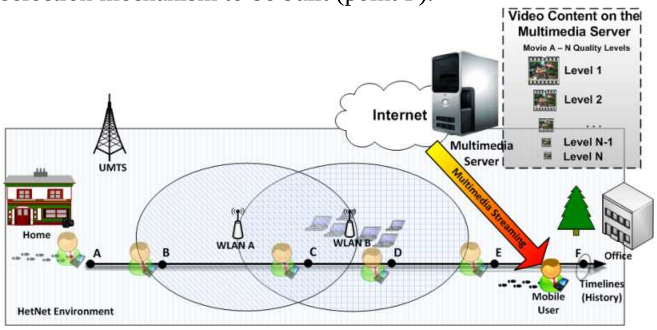

Fig. 4. Reputation-based Network Selection – Example Scenario

B. *Setup Parameters and Asuumptions*

In the above presented context, the user profile in use for the network ranking mechanism includes the following settings: the preferences for energy, quality and monetary cost and the minimum and maximum cost the user is willing to spend for multimedia services, such as C_{min} = 0, and C_{max}= 1 respectively. The costs for each of the three networks considered as in Fig. 4 are set to: WLAN A – 0.2 cents per unit of data, WLAN B – free hot-spot, and UMTS - 0.9 cents per unit of data. The user is running a 600 seconds long MPEG-4 multimedia stream, and it is assumed that the Multimedia Server stores five different quality levels of the multimedia stream with the encoding settings presented in Table I [15]. Thus, Th_{min} = 0.120Mbps, Th_{max}= 1.920Mbps, and Th_{req}= 0.480Mbps. In terms of energy consumption of the mobile device, the values for the energy consumption rate per unit time (r_t) and the energy consumption rate for data/received stream (r_d) under various network conditions are listed in Table II [15]. The values for E_{max} and E_{min} are 983.4 Joules and 434.75Joules, respectively [15].

TABLE I. Encoding Settings for Multimedia Levels

	Encoding Parameters				
Quality Level	**Video Codec**	**Overall Bitrate [Kbps]**	**Resolution [pixels]**	**Frame Rate [fps]**	**Audio Codec**
QL1	H.264/ MPEG-4 AVC Baseline Profile	1920	800x448	30	AAC 25 Kbps 8 KHz
QL2		960	512x288	25	
QL3		480	320x176	20	
QL4		240	320x176	15	
QL5		120	320x176	10	

TABLE II. R_T AND R_D VALUES FOR EACH INTERFACE

Interface		r_t (W)	r_d (J/KB)
UMTS		1.058	0.000388
WLAN A No Load	Near AP	0.6341570	0.0003869
	Far AP	0.6690961	0.0002377
WLAN B Loaded	Near AP	0.6641148	0.0003660
	Far AP	0.7115433	0.0004889

Using the values for r_t and r_d for each interface and network conditions, the values for the computed energy E for each quality level, using eq. (2) are listed in Table III. As the UMTS network has a maximum theoretical data rate of 384kbps, a subset of three out of the five quality levels were considered for streaming over UMTS.

TABLE III. COMPUTED ENERGY [JOULE]

	WLAN				UMTS
	No Load, Near AP	**No Load, Far AP**	**Load, Near AP**	**Load, Far AP**	**Mobile Network**
QL1	861.1	875	897	1300	N/A
QL2	624.2	625	658	841	N/A
QL3	501.2	486	541	614	747
QL4	440.8	439	478	515	691
QL5	412.9	420	438	468	663

C. Impact of User Preferences on Network Selection

In order to study the impact of user preferences, represented by the weights' values, on network selection terms the case of Point C in Fig. 4 is considered, where the mobile user has a choice of three networks: UMTS, WLAN A (No Load and Far from AP setup), WLAN B (Load and Near AP setup). Three case studies are considered: (a) *balanced user* with w_e=0.4, w_q=0.4, w_c=0.2, where the user is willing to pay a certain amount while maintaining a balance between the quality level and the energy consumption; (b) *equal interest user* with w_e=0.33, w_q=0.33, w_c=0.33, where the user equally cares about the three criteria enery, quality, cost; and (c) *cost-oriented user* with w_e=0.1, w_q=0.1, w_c=0.8, where the user is cost aware and has a strict budget. The overall score function computed with eq. (1) for all three case studies are listed in Table III.

TABLE IV. OVERALL SCORE RESULTS

		QL1	QL2	QL3	QL4	QL5
Balanced User	**WLAN A**	0.5119	**0.7365**	0.6010	0.3965	0.2382
	WLAN B	0.4774	0.7349	0.6039	0.3993	0.2427
	UMTS	N/A	N/A	0.4132	0.2827	0.1741
Equal Interest User	**WLAN A**	0.5656	0.7636	0.6457	0.4581	0.3009
	WLAN B	0.5434	**0.7756**	0.6596	0.4689	0.3110
	UMTS	N/A	N/A	0.4370	0.3195	0.2142
Cost-Oriented User	**WLAN A**	0.7816	0.8560	0.8136	0.7332	0.6455
	WLAN B	0.8312	**0.9259**	0.8815	0.7949	0.7019
	UMTS	N/A	N/A	0.5120	0.4657	0.4126

The results show that in case of a balanced user, out of the three networks and the five quality levels, the proposed network selection mechanism will select QL2 on WLAN A, meaning that the user is willing to pay 0.2 cents/unit of data to receive QL2. Compared to the case of selecting the highest quality level, QL1 on the free network, the user could achieve up to 30% in energy savings. In case of equal interest user and cost-oriented user, the outcome is the same, and both user preferences will select the free network, WLAN B with QL2. In this case, compared to selecting QL1 on the free network, a 26.6% decrease in energy consumption is achieved while the impact on video quality is not significant. Thus, by using the multiplicative exponential weighted function in eq. (1) a good trade-off between energy-quality-cost is achieved regardless the user preferences on the criteria.

D. Impact of Importance Tolerance on the Interaction Weights

As previously mentioned, in order to strengthen the cooperation between users and networks and keeping track of the past experience, a network reputation factor was defined, as in eq. (7). By defining the interaction weight in eq. (8), the reputation computation becomes more dynamic preventing the case in which the operator would degrade the offered QoS to the mobile user after gaining high reputation in the past. For example, imagine the scenario where a mobile user has a past history of six interactions with a network. The weights for each interaction are computed using eq. (8) with n=6 and using different values for ρ (e.g., 1, 2.5, 5, and 10). By varying the values of ρ the importance tolerance of the weights in the final decision is analyzed. Figure 5 illustrates the assigned weights for each of the six interactions for varying values of ρ. On the X axis the number of interactions is represented, with 0 being the most recent interaction and 6 being the oldest interaction. As only the last 6 user-network interactions are considered, the 7^{th} interaction's (represented by 6 on the X axis) weight is zero. On the Y axis the assigned weight is illustrated, the most recent interaction is the most important, its weight being 1. As it can be noticed, for small values of ρ, (e.g., 1 or 2.5) the assigned weights' utility is gradually becoming less important as the interactions become older. For high values of ρ, (e.g., 5 or 10) the assigned weights' utility is decreasing faster, almost linearly, as the interactions become older. In this work, the value of ρ is considered to be 2.5 as it presents a more gradual decrease in the importance tolerance of the user-network interaction.

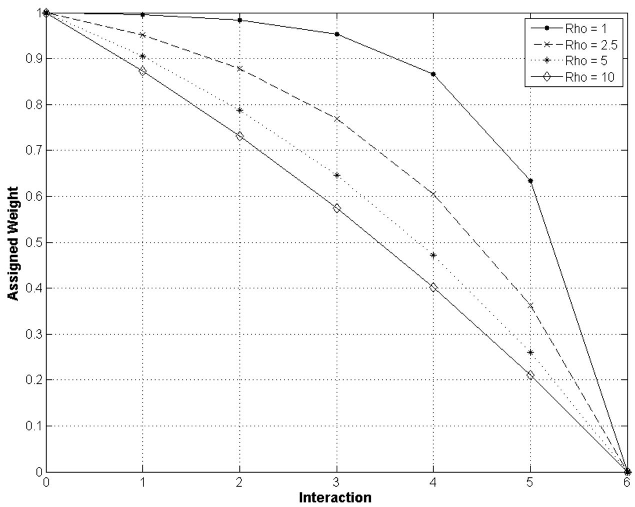

Fig. 5. Interaction Weights for Different Values of ρ

The network reputation factor for each of the networks considers the last *n* user-network interactions. These n interactions can be more frequent with some of the networks more than with others. Meaning that the interactions with a certain network can happen over the last few days whereas the interactions recorded for another network could have taken place over the last year. This aspect however is not considered by the reputation factor presented in this work but it could be considered as part of future work.

E. Impact of Network Reputation on Network Selection

The diversity in user preferences and application requirements will generate different reputation factors for the networks they visit. Considering again the scenario in Fig 4., and assuming that the mobile user had six user-network interactions, we analyze how the network behavior will impact the network reputation utility function in eq. (6). It is assumed that the expected utility from WLAN A QL2 is 0.7365 as listed in Table IV, and that over time WLAN A offers a degraded QoS, taking advantages of the good reputation from the past. This is reflected in the experienced utility U_E after each interaction along with the interaction weights values, listed in Table V, where interaction 0 is the most recent user-network interaction. The network reputation factor for WLAN A is then computed using eq. (7), resulting in $\gamma_{WLAN\text{A}}$ = 0.5128. Thus the next time the network selection process takes place, the overall score is calculated with the utility-based reputation-oriented function in eq. (6), where the expected utility is 0.7365, however with the new reputation factor $\gamma_{WLAN\text{A}}$, the new score for WLAN A will drop to 0.377. Thus even though WLAN provided the expected QoS to the mobile user, the recent degradation in QoS affected its reputation reducing its score value and its probability of being selected in the future network selection process.

TABLE V. EXPERIENCED UTILITY WITH WLAN A

Interaction *j*	5	4	3	2	1	0
Experienced Utility U_E	0.7365	0.7201	0.7105	0.700	0.698	0.589
Interaction weight *w*	0.36	0.61	0.77	0.88	0.95	1

V. CONCLUSIONS AND FUTURE WORK

This paper proposes URAN, an **U**tility-based **R**eputation-oriented **A**ccess **N**etwork selection strategy for HetNets. URAN combines the utility theory with the reputation theory to build a reputation-based system between users and networks in a HetNet environment. URAN takes into consideration user preferences, energy consumption of the mobile device, the quality of the multimedia applications, and the monetary cost of the network to select the best value network that satisfies the users' needs and provides incentives for the user-network interaction to maintain cooperation in long term by integrating a reputation-based system. Numerical results show that URAN achieves a good trade-off between energy-quality-cost acting in the user's best interests.

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