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Performance of Handover for Multiple Users in Heterogeneous Wireless Networks

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***Abstract*—Handover solutions ensuring seamless connectivity and high user-perceived quality of service for a given application context are essential for multi-mode wireless devices in heterogeneous wireless network environments. A critical handover step, the network selection decision, is automatically and transparently made in the user's terminal, aiming to keep the user "always best connected". We propose Quantified Adaptive Delay Selection (QADS), a novel multi-user-aware handover algorithm that maintains high quality of service levels for mobile users performing handover in heterogeneous wireless network environments. QADS is a user-centric solution buildt on the IEEE 802.21 Media Independent Handover standard. It addresses the problem of multiple mobile nodes performing network selection independently, using the same selection algorithm. With innovative mechanisms based on adaptive contention and randomization, the algorithm increases overall user-perceived quality of service.**

I. INTRODUCTION

Future wireless networks involve multi-mode devices connected to networks of different radio access technologies. Handover, the transfer of a call session between networks, involves selecting between available networks, taking into account their characteristics as well as application requirements, device capabilities, and user preferences [1].

With ubiquitous mobile networking, scenarios of multiple users switching networks simultaneously become more frequent. The users may leave a congested network or move away from an access point, e.g., a group of students with similar preferences (low cost, high bandwidth) leaving a lecture room and accessing the same type of content, such as online notes.

This paper introduces the Quantified Adaptive Delay Selection (QADS) terminal-controlled handover algorithm, which chooses networks by taking into account the impact of other users operating in the same area, so that the best Quality of Service (QoS) is obtained. It is an innovative solution that achieves high QoS when mobile devices perform simultaneous handover in an infrastructure-based heterogeneous environment. The focal points of the algorithm are a QoS-aware adaptive delay and a random factor to avoid ping-pong.

II. RELATED WORK

While the problem of vertical handover has seen increased interest, most research addressing terminal-controlled network selection does not consider multiple users. An exception is the game-theoretical approach of Cai and Liu [4] for ad-hoc networks. Unlike the proposal here, their algorithms require knowledge of other users' traffic loads and network selections.

Dutta et al. [5] perform proactive handover using the mobile's location. Performance is improved compared to selection by signal-to-noise ratio but the solution has sizeable overhead, tracking all networks and connecting to several at once. Yoo et al. [6] use neighbor network information and the MIHF [2] to generate proactive triggers in time to allow seamless handover, but ignore selection criteria such as cost, user preference, or application type. The connectivity opportunity selection of Cavalcanti et al. [7] uses network state information and a mobile profile based on application requirements.

The utility function introduced by Wang et. al. [8] uses weights and parameters represented on the logarithmic scale. Of the parameters considered, security is not available through MIH and is therefore not considered in this paper. The quality functions with heterogeneous criteria from [7] differ by application type and device mobility. QADS uses a generalized formula, with weights depending on application type and bounds based on recommendation G.1010 [3].

III. QADS - PROPOSED NETWORK SELECTION ALGORITHM

A. Design approach

Recent work on terminal-controlled handover does not consider the actions of other users operating in the same environment, namely the possibility that several users select and connect to the same network in the same timeframe. To account for this, QADS delays the connection to the best candidate network in each mobile node. This delay, reasonable for a vertical handover, is set inversely proportional to the benefit that the selected network brings to the user. When the delay has elapsed, the mobile node will re-compute the QoS to ensure that the network choice is still the best for this node.

In the case where a number of nodes have the same preferences, the computed delay could be the same. This would result in all these nodes connecting to the same network in the same timeframe, possibly overloading the new network. In QADS, this problem is solved by monitoring the QoS before, during, and after handover. In situations when the new

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QoS is far less than the expected QoS, QADS infers that a large number of nodes may have simultaneously handed into the same network. This is resolved by using a random decision to stay with the new network or to handover to an alternative network, as opposed to all nodes switching networks with the possibility of ending up in an unstable ping-pong state. Some nodes will likely decide to move from the network so it will be less strained and will better service the nodes that stay. Nevertheless, it is possible that the network quality is reduced for other reasons, however, in this case, the algorithm relies on the link going down or link down triggers [2].

B. The quality function

QADS computes a weighted score, the Application-Network Match (ANM), for each candidate network N_i, based on information received from the application layer and the MIIS.

$$ANM(N_i)=\begin{cases}0, & p_{kR}(N_i)<0\\ \displaystyle\sum_{k=1}^{m} w_k\cdot p_{kR}(N_i), & p_{kR}(N_i)\geq 0, \displaystyle\sum_{k=1}^{m} w_k=1\end{cases} \tag{1}$$

In (1), $p_{kR}(N_i)$ is the normalized value that the network N_i provides for parameter k, w_k is the corresponding weight attributed by the application/user, and m is the number of parameters considered relevant for the application. Candidate networks that fail minimum criteria are eliminated by a negative score $p_{kR}(N_i)$, so that for example a very low network cost does not outweigh a poor, unacceptable throughput rate. This is achieved using minimum and maximum utility thresholds p_{kUmin} and p_{kUmax} between which the actual network parameter $p_k(N_i)$ is considered acceptable to the application.

For parameters to be maximized ($p_{kUmin} \leq p_{kUmax}$),

$$p_{kR}(N_i)=\frac{\min(p_k(N_i),p_{kUmax})-p_{kUmin}}{p_{kUmax}-p_{kUmin}} \tag{1a}$$

For parameters to be minimized ($p_{kUmin} \leq p_{kUmin}$),

$$p_{kR}(N_i)=\frac{\max(p_k(N_i),p_{kUmax})-p_{kUmin}}{p_{kUmax}-p_{kUmin}} \tag{1b}$$

The upper and lower bounds for a parameter are obtained from the application layer depending on the application [3], user and device. Values better than p_{kUmax} bring no benefit for user or application. Values worse than p_{kUmin} are unfit, resulting in the elimination of the candidate network.

C. Backoff delay

If all devices select and handover to the same network within a short interval, the network may become overloaded resulting in a drop in link quality. It may be then that all users switch networks again leading to ping-pong. A back-off delay (D) is introduced (2) to avoid simultaneous handover:

$$D=\begin{cases}MHT\cdot(1-(ANM(N_s)-ANM(N_{crt}))), & ANM<GT\\ 0, & ANM\geq GT\end{cases} \tag{2}$$

D prioritizes handover based on the estimated benefit of the selected network N_s over the current network N_{crt}. The delay is set to be smaller than the maximum handover time (MHT), an interval sufficient for a vertical handover, as determined e.g., in [6]. If, once the delay elapses, $ANM(N_s)$ is still larger than $ANM(N_{crt})$, the device connects to N_s. The handover has high priority and is not delayed when the gain is above a heuristic gain threshold GT.

D. Random decision

If all users in a group have similar applications (D approximately equal) they will connect to the same network within a short interval, overloading it. To avoid a number of nodes simultaneously handing back to the original network and perhaps causing a ping-pong state, the ANM value of the new network is compared to its expected value (the ANM value for the network stored right before the delay timer is set) after the connection is established, and if it is worse by more than DT (Drop Threshold) the node randomly decides whether to stay on the network or not.

E. Integration with the IEEE 802.21 MIH function

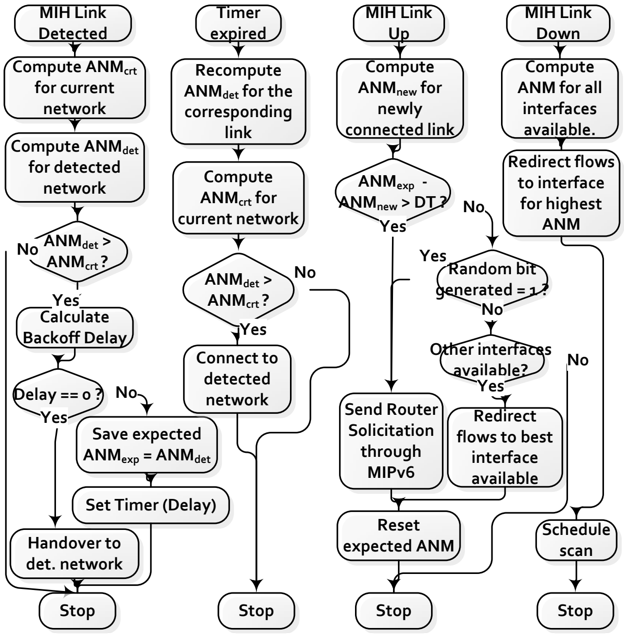


Fig. 1. Flowchart of QADS algorithm

QADS uses the Media Independent Handover function of the IEEE 802.21 draft [2] and requires a cross-layer architecture: IEEE 802.21 signaling to interface with the physical layer and minimum/maximum values for each of the network parameters from the application layer. The latter are presumed to be well-determined for a given combination of user/device/application at a given time. Readings of the network parameters are obtained from the Media Independent Information Service [2] and are used as inputs for the ANM calculation. The triggers of the Media Independent Event Service [2] notify the terminal of changes in link characteristics. The Media Independent Command Service [2] allows the device to change and configure its links according to the algorithm.

Figure 1 displays how the algorithm reacts to the MIES events. When a new link is detected, its ANM value is compared with that of the available networks. If it is greater, the back-off delay is computed, and a timer is set. When it expires, the comparison is repeated and if the detected network still offers better quality, the connection is established. After the link up event is triggered and if a considerable degradation in quality (DT) is detected, a random decision is made on whether to keep the connection to the network.

IV. TESTING OF THE QADS ALGORITHM

Testing was carried out using Network Simulator version 2.33 [9] with the NIST mobility add-on [10]. Two other algorithms were run on the same platform: the Always Cheapest Selection (ACS) and a QoS-based algorithm named the Polled Network Quality-based Selection (PNQS) which periodically estimates network quality and selects the best network, according to the formula adapted from [8]:

$$QoS(N_i) = w_c \ln(\frac{1}{c_i}) + w_b \ln(\frac{1}{B - b_i}) \qquad (3)$$

In (3), w_c and w_b are weights for cost and bandwidth respectively, B is the bandwidth required by the terminal, b_i is the actual bandwidth received by the terminal, while c_i is the cost of the network. For QADS, throughput and cost were considered relevant parameters, each having a 0.5 weighting in the ANM function.

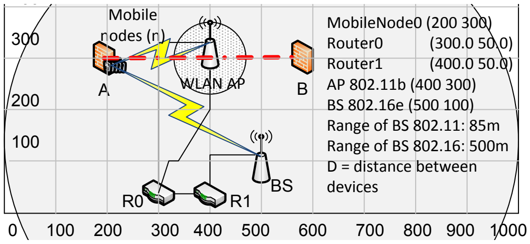


Fig. 2. Simulated scenario

In the test scenario considered (Figure 2) nodes are moving over a distance of 400 m, with a speed of 1 m/s while downloading MPEG content, modeled as a 0.8 Mbps constant bit rate application over UDP. The setup contains two networks, a WLAN and a WiMAX with coverage ranges of 85 m and 500 m respectively (typical ranges). The nodes start and remain within the WiMAX coverage and cross the coverage area of the WLAN. The WLAN is free, while 3 ¢/Gb is charged for the WiMAX. The maximum acceptable price is set to 10 ¢/Gb ($p_{costUmin}$), the free network offers the highest utility ($p_{costUmax}$=0). Maximum handover time was set to 500 ms [6]. For throughput, $p_{throughputUmin}$=0.064 Mbps and $p_{throughputUmax}$=0.8 Mbps. Gain Threshold GT=0.5, Drop Threshold DT=0.3, while the probability of staying on an unsuitable new network is 0.5.

Traffic starts 5 seconds into the simulation, and after 10 seconds, the nodes start to move. Around second 127, the nodes gradually come into the range of the AP. Depending on the handover algorithm, some nodes may handover to the WLAN. At second 285 the nodes begin to leave the coverage of the AP, at which point they lose their WiFi connection and handover back to the BS of the WiMAX network.

A. *Test-case I: 5 aligned nodes*

In this test case five users move in single file, with distances between them of 0.1 m, 0.5 m, and 5 m in different runs. With ACS, all the nodes handover from the WiMAX to the WLAN, overloading it. PNQS always selects the network that appears the best, but because there are more nodes involved, some of them ping-pong. On the other hand, when QADS is used, some nodes either do not connect to the WiMAX (when the inter-node distance is 5 m) or switch back to the WiMAX as a result of the decreased quality in the WLAN.

B. *Test-Case II: 9 nodes in lines of threes*

This test case considers nine nodes, spaced by 0.4 m within each row of three and by 4 m between rows. Due to the node alignment, users in the same row perform the network selection decision at the same time. With ACS, the nodes connect to the WLAN until it gets so overloaded that it cannot transmit acknowledgements to new users that are trying to connect, only then will these users remain on WiMAX. When using QADS, the first row performs handover to the WLAN. The second row of users will all connect to the WLAN simultaneously. On detecting the drop in expected quality, the random decision is triggered in each node. Depending on the decisions, the WLAN may now be at full capacity. Nodes in the third row will either ignore the WLAN or will all perform handover and then re-compute the ANM, which again leads to a random decision for each.

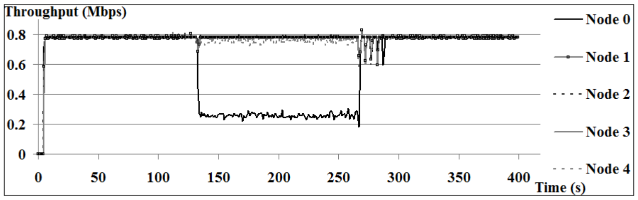
C. *Test-Case III: 14 nodes in a group*

This test case features more mobile users, placed asymmetrically, with distances of 1 m on the x axis and 5 m on the y axis. With ACS, nodes switch to the WLAN until it is completely blocked, whereas QADS results in a more even distribution of the nodes, since a terminal either connects to the WLAN to find a better quality of service or to switch back, or it doesn't connect to the WLAN at all as a result of the computed ANM function.

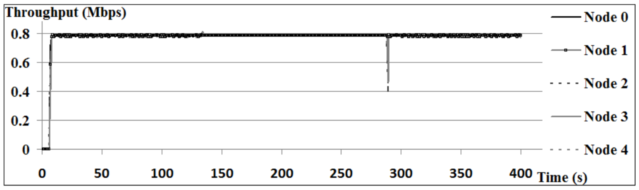
D. *Results*

Figure 3(a-c) shows the node throughput for test case I, with ACS, QADS and PNQS respectively. As illustrated in Figure 3a, one node is disadvantaged in terms of throughput, while the jitter is substantial for all nodes. In Figure 3c, the ping-pong is obvious. With QADS, the previously disadvantaged node has the benefit of maximum throughput needed for the application although it has the disadvantage of paying more. Also, there is less data loss during handover and less jitter for all nodes. Compared to PNQS, the number of handovers was reduced from 118 to 8 on average.

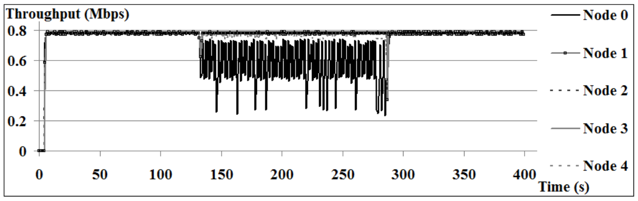
Table I shows the results for test case I. The total throughput for the group of users offers an insight on how well the



(a) Throughput for each node using ACS



(b) Throughput for each node using QADS



(c) Throughput for each node using PNQS

Fig. 3. Comparative throughput results for the three algorithms

bandwidth from the available networks has been exploited. Total throughput and throughput variation for each node reflect the quality that each mobile device receives. For test case I, QADS offers an advantage over the ACS and PNQS strategies. Nevertheless, one node will pay roughly 60% more for a 50-fold reduction in jitter and a 20% improvement in throughput. As displayed in Table II, the fairness of the throughput distribution is improved. For MPEG applications, jitter is a particularly significant parameter hence the relevance of displaying the standard deviation of throughput.

TABLE I
PERFORMANCE INDICATORS FOR CASE I (D=0.1m)

Performance indicator	*ACS*	*PNQS*	*QADS*
Average overall throughput (Mbps)	3.6592	3.7636	3.8521
Std. dev. of overall throughput	0.4934	0.4593	0.4408
Total traffic sent (Mb)	1463	1505	1540
Total data loss at AP (Mb)	9.6159	4.4965	1.6880
Data loss (% of total traffic)	0.6569	0.2986	0.0109

TABLE II
NODE STATISTICS FOR CASE I (D=0.1m)

Throughput (Mbps)	*Avg ACS*	*Avg PNQS*	*Avg QADS*	*Stdev ACS*	*Stdev PNQS*	*Stdev QADS*
Node 0	0.5999	0.6988	0.7812	0.2476	0.1391	0.0042
Node 1	0.7787	0.7794	0.7812	0.0186	0.0243	0.0040
Node 2	0.7794	0.7801	0.7803	0.0162	0.0197	0.0201
Node 3	0.7783	0.7793	0.7804	0.0143	0.0172	0.0167
Node 4	0.7716	0.7763	0.7806	0.0182	0.0159	0.0137

TABLE III
PERFORMANCE INDICATORS FOR CASE II

Performance indicator	*ACS*	*PNQS*	*QADS*
Average overall throughput (Mbps)	5.9805	6.7166	6.8821
Std. dev. of overall throughput	1.6282	0.9945	0.8552
Total traffic (Mb)	2392	2686	2752
Total data loss at AP (Mb)	57.2309	21.2879	13.2055
Data loss (% of total traffic)	2.3923	0.7923	0.4797

TABLE IV
PERFORMANCE INDICATORS FOR CASE III

Performance indicator	*ACS*	*PNQS*	*QADS*
Average overall throughput (Mbps)	6.4824	8.2146	7.9826
Std. dev. of overall throughput	1.7983	1.1445	0.9799
Total traffic (Mb)	2268	2875	2793
Total data loss at AP (Mb)	126	52	82
Data loss (% of total traffic)	5.5890	2.9610	1.8418

Table III shows that for test case II, QADS improves the total average throughput for all users by more than 15%, over ACS. Compared to PNQS, QADS dramatically reduces the number of handovers: from a total of 251 to 14 on average.

Table IV shows that in test case III QADS outperforms ACS: combined throughput for all users is increased by more than 20% and a substantial decrease in packet loss is achieved.

V. CONCLUSION

This paper examines the problem of terminal controlled network selection algorithms in the context of multiple mobile nodes moving together in the range of several wireless networks. The solutions are offered in the form of a novel network selection algorithm based on a quality of service function and randomization. The initial comparison of the proposed QADS against the ACS algorithm has showed a clear improvement, both in terms of individual and overall QoS (based on group throughput and packet loss), while the comparison with the more elaborate PNQS algorithm showed that QADS is effective in minimizing ping-pong.

Future work will involve more tests on social gain and fairness, with other applications and user groups. Additionally, the algorithm will be tested against other intelligent network selection algorithms with similar objectives.

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