Paper

Adaptive handover control in IP-based mobility networks

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Abstract — In this paper, we propose framework for an adaptive handover control architecture (AHCA), which aims at enhancing overall IP handover performance while maximising utilisation of resources in wireless access networks. The IP handover procedures in the AHCA adapt dynamically to network conditions, as well as to a wide range of user profiles and application quality of service (QoS) requirements. To confirm our expectations that the AHCA will bring performance benefits in heterogeneous mobile IP networking environment, we have investigated basic performance characteristics of different handover mechanisms. The preliminary simulation results demonstrate that the AHCA will bring significant performance improvements as compared with non adaptive IP handovers.

Keywords* — *mobile networking, mobile IP, handover performance, adaptive handover control.

1. Introduction

Mobile IP (Internet Protocol) [11, 12] provides network layer transparent mobility support to mobile nodes (MNs) roaming across different IP subnetworks. Among many deployment issues of mobile IP, the support for micro (local) mobility and seamless handover have been in focus of many research activities over a number of recent years. While many different proposals such as in [8] have been published thus far to address these issues, it is generally accepted that one solution can not fit all situations and requirements, especially in environments where various mobility mechanisms and quality of service models are mixed together [1] in heterogeneous wireless access networks [9, 13].

There are several reasons why a smart, adaptive handover control is needed:

- With adaptive handover control, various handover strategies can be mixed to take advantage of what each technique/strategy can offer, depending on the availability of the technique in a given access network and the network, user and application preferences.
- Adaptive handover control will improve resulting handover performance as the handover procedures selected will best reflect the dynamically varying network operating conditions.
- A number of mobility mechanisms have been proposed to achieve effective global and local mobility management. As a consequence, there is a strong need to harmonise the use of these different mechanisms and promote interoperability across the entire network.
- Normally, some coupling between layer-3 and layer-2 is required (layer-2 support) to achieve best handover performance with the different access network technologies.
- Heterogeneous wireless access technologies require specific handover strategies suited for each wireless access network, resulting in a need for common framework to make handover across the different access technologies seamless.

To best adapt to the current operating conditions and the access network environment where a MN has just moved into, it would be preferable if a smart (adaptive) handover control mechanism [3] could provide flexible service depending on dynamically varying requirements of each traffic flow and application session involved [2]. For this purpose, we have designed the adaptive handover control architecture. As a core part of the architecture, the adaptive handover engine takes inputs from several input pre-processing modules, e.g. network resource information from the network resource prober, traffic QoS attributes from the traffic classifier, user preferences information from the user input handler, and policy information from the policy input handler. Then, it selects the best combination of handover mechanisms using a handover adaptation algorithm, so that the chosen handover strategy produces the best performance for the user, while minimising the use of shared network resources. The architecture has been inspired by the related research in the field of mobile IP handoff control, such as programmable handoffs [4], policy-enabled handoffs [14], and many other adaptive or feedback-based control approaches [5–7].

As an example, the AHCA can be applied to the environment where interoperation between terrestrial and satellite wireless mobile networks is required [10]. In a simple scenario of a satellite-to-terrestrial handover case, the optimal handover control would force handover as soon as an available terrestrial mobile network can be found, thus increasing user satisfaction in terms of both performance and cost. The details of our example scenario would change according to varying conditions surrounding the MN, thus would require some form of adaptation which can be accomplished within the AHCA.

The design goals for the AHCA can be summarised as follows:

- Seamless (both low-loss and low-latency) handover, adaptive in respect to specific requirements of traffic type and its explicit or implicit QoS attributes.
- Microflow based handover control, supporting both user and terminal mobility.
- Fairness- or priority-based usage of resources (e.g. bandwidth, buffer memory, power consumption etc.) while providing reasonable level of QoS.
- Graceful degradation of QoS in cases of resource shortages or unavailability of required capability.
- Dynamic adaptation in pace with varying conditions of operating environments and MN itself – automatic or interactive change of operating parameters.
- Backward compatibility with existing standard or de facto standard protocols.
- Extensibility to cover proposed and future handover algorithms and micro-mobility mechanisms.
- Deployability across a wide range of mobility networks including 802.11 WLAN (wireless local area network) and next generation IP-based cellular networks.

The organisation of this paper is as follows: in the next section, we describe the details of the AHCA. In Sections 3 and 4 we explain the simulation setup and present the example network topology used in the simulation study. We then follow with some preliminary simulation results and their analysis. Finally, we give some concluding remarks and comments on future directions in this research.

2. Adaptive handover control architecture

Figure 1 shows the basic concept of adaptive handover control (components and flows). The handover adaptation algorithm produces optimal set of handover strategies according to various inputs. Various inputs – probed network information, traffic type and QoS attributes of a traffic flow, policy control information, and user preference – are fed to the adaptation algorithm to reflect the environment within which the handover is to occur. Besides these regular inputs, there can be two other possible inputs from the feedback loop and re-adaptation loop. Feedback loop provides performance measures to the adaptation algorithm for the purpose of fine-tuning of future handovers. Re-adaptation loop could be used as a calibration path due to short term changes of surrounding network conditions. To speed up the operation, re-utilisation path can be used to save time and resources by utilising a hashed cache table, which is updated during a few previous iterations of the control algorithm. That could save repetitions of control computations and reduce the time overhead added to the handover by the handover control procedures.

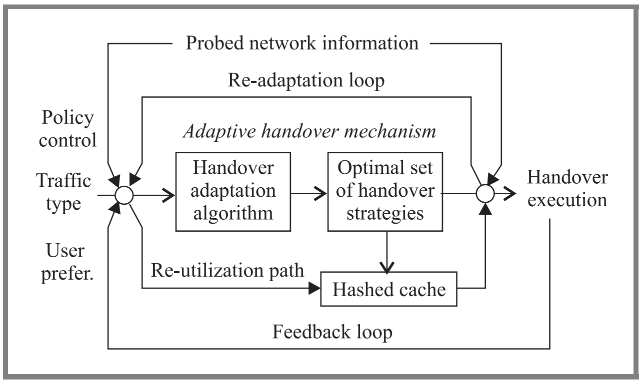

Fig. 1. The concept of adaptive handover control (AHC).

In accordance with the basics described above, we have constructed the AHCA as shown in Fig. 2.

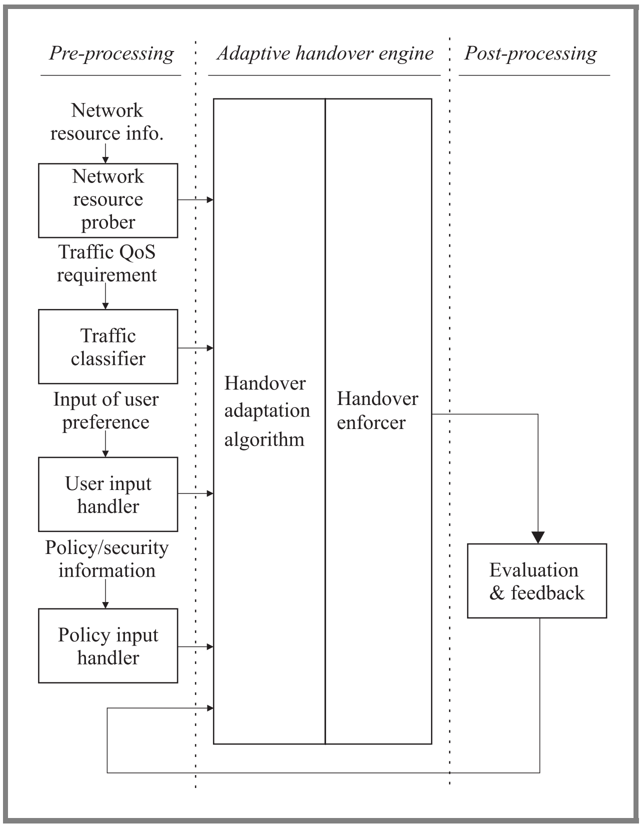

Fig. 2. Adaptive handover control architecture.

The basic operation of the AHCA is as follows. The AHCA:

a) gathers input information;

b) processes inputs to choose the best set of handover mechanisms, and the best parameters for the mechanisms selected;

c) controls the execution of the chosen handover by the MN and mobility agents (MAs);

d) (optionally) feeds back some performance information into the handover adaptation engine.

The component processes of the AHCA reside mainly in MAs and co-operate with components of the AHCA residing within the MN. In most cases, some form of communication needs to occur between MA and MN (or between MAs) to control the handover execution, and to exchange information that will aid handover process. This communication may take the basic form of handshaking messages and is described in detail in Sections 2.1 and 2.4.

The AHCA is designed to be an open architecture so that the internal details of its component modules can be substituted as long as the basic interfaces between modules are maintained. In this way, new or more enhanced mechanisms can be used to increase the performance benefits, or mechanisms not available in the given access network environment may be substituted with available ones at the expense of some performance degradation.

Below, we give brief descriptions of the AHCA component modules, outlining the major inputs and outputs and the main functionality of each module.

Network resource prober (NRP): Probe available network resources, using the dynamic network resource probing protocol (DNRPP), in the neighbouring access network and the MN's home network.

Traffic classifier (TC): Get QoS attributes via signaling protocol related to specific microflow and/or sample data traffic to determine the type of traffic and associated QoS attributes.

User input handler (UIH): Process user preferences input interactively or via a built-in static interface.

Policy input handler (PIH): Query network policy/ security/ AAA (authentication, authorisation and accounting) control information and manage local policy information (in the form of configuration table or by dynamic gathering).

Handover adaptation algorithm (HAA): Determine the optimal set of handover strategies in respect to the obtained input criteria, and feed them to the handover enforcer.

Handover enforcer (HEnf): Enforce handover according to the given set of strategies.

Evaluation and feedback processor (EnF): Obtain performance metrics, evaluate against predefined threshold, and feed back to the engine.

In the following subsections, the component modules of the AHCA are explained in more detail.

2.1. Dynamic network resource probing protocol

The dynamic network resource probing protocol can be considered a kind of network resource discovery protocol used by the network resource prober module of the AHCA.

The objective of the DNRPP is to probe network resource information dynamically and in co-operation between MN and MA. Its operation mode can be passive or active. In passive mode, some information is advertised periodically from MA to nearby MNs in an unsolicited manner. In active mode, MN solicits network resource information from nearby MAs. The MAs receiving the request should respond with requested resource information unless security association between MA and MN has not been established or is broken.

The network resource information will be used as an input to the HAA as well as to the re-adaptation loop of the AHCA. It may also be used in prediction and preparation of future handovers. To effectively aid the various uses of network resource information, it is important to select the information items most useful to the AHCA and define efficient format of the information as to not consume too much network bandwidth in the process of probing. A few candidates for the components of the network resource information are delay-distance measure between probe initiating node (e.g. MN, FA – foreign agent) and probe responding node (e.g. FA, HA – home agent, CN – correspondent node), and capabilities supported by the MN or the MA(s).

2.2. Traffic classifier

The traffic classifier consists of four component modules; three of them are input processor modules, and remaining one is QoS level classifier module. One of the input processor modules, the QoS signal handler, examines explicit QoS signaling information from various QoS signaling protocols (e.g. resource reservation protocol Path/Resv) for the specific microflow concerned, and feeds QoS attributes specified for the microflow to the traffic QoS level classifier module. The other two input processors are the header examiner and the payload examiner, which respectively examine some IP header fields and a few starting sequences of payload traffic to get traffic type information and associated QoS attributes, and then feed this information to the traffic QoS level classifier module. Finally, according to traffic type and associated QoS requirements attributes, the Traffic QoS level classifier module produces quantised level of QoS requirements (a value selected from a range of predefined QoS levels) and this output is fed to the adaptive handover control engine.

2.3. Handover adaptation algorithm

In general, the essence of the first stage of fast handover is finding appropriate MA(s) to be in charge of mobility support in the access network area where MN is expected to move or has just arrived. Then, MN has to decide the most appropriate time to effect the seamless handover. Once handover decision is made, the next step is to choose the best handover strategy i.e. both the handover mechanisms (algorithms) and the related set of parameters. These steps are listed below.

1. Select the best MA (FA) to support the handover.
2. Decide the best time to execute the handover.
3. Choose the best set of handover mechanisms available for this handover.
4. Select the best set of parameters for the chosen handover mechanisms.

The handover adaptation algorithm focuses on the last two steps of the fast handover, choosing best handover mechanism(s) and selecting the best parameter set for the selected handover mechanism. The first two steps, dealing with movement detection and handover decision, are not directly covered by the HAA itself. Figure 3 shows the basic operation of the HAA in respect to the last two steps of the fast handover.

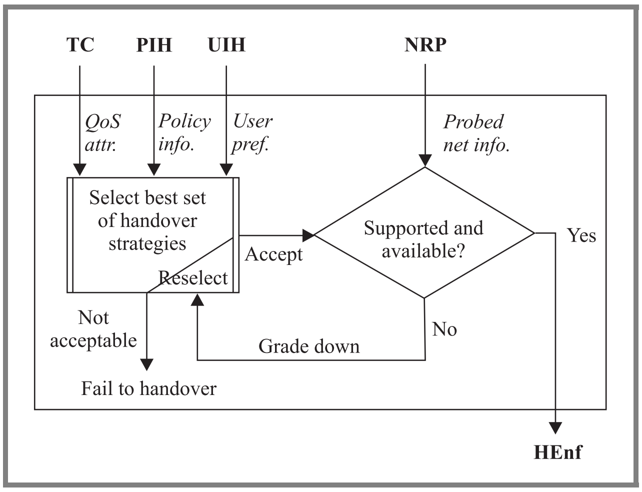

Fig. 3. Operation of the handover adaptation algorithm.

2.4. Handover enforcer

The handover enforcer module provides direct handover control services for the actual handover execution occurring between a MN and one or more of MAs. Depending on the chosen set of handover mechanisms, more than one MA could be involved in the process of exchanging handover control messages.

The messages exchanged between the MAs and the MN can be similar to those used in basic handover control, and thus can be combined with, or substituted for, these basic messages as needed. This may help reduce the overall handover signaling load incurred by the adaptive handover.

2.5. Evaluation and feedback

The evaluation and feedback process is a key component in the *closed-loop* AHCA control system. Without this process, the AHCA becomes merely an *open-loop* control system that has no ability to self-adjust and optimise its own performance. An open-loop AHCA could never directly utilise the measures of its performance, normally collected while the system operates. However, for the purpose of handover control, we can still call the open-loop AHCA adaptive, since it adapts the handover execution according to varying inputs collected from its network environment; in such case the adaptive handover engine would be adjusted manually rather than automatically through the use of feedback component.

In order to achieve effective, fast and dynamic control of the system, while maintaining acceptable stability and overall system efficiency, it is important to make a careful selection of the performance measures that are collected and fed back to the control algorithm. While some conventional performance measures may include packet loss rate, end-to-end transmission delay, delay variance (jitter), throughput, success/failure rates (per call or per handover) and resource usage levels, we can also consider the following second-order performance measures: signaling load, user satisfaction level and (handover and/or network access) cost function.

2.6. Security considerations

In the AHCA, interactions between MNs and MAs are essential part of dynamically probing network resources and of enforcing/coordinating the actual handover. The fundamental importance of these to the network operation means that some kind of security association must be formed between the interacting agents to avoid security attacks. This paper assumes that the security mechanisms specified for the standard mobile IP protocol [11] can be used as part of the AHCA.

3. Simulation setup

3.1. Network topology

Figure 4 shows the network topology we have used as a basis for our simulations under OPNET network simulation environment, to investigate the basic characteristics of mobile IP handover mechanisms. In the figure, the *R_x* denotes border routers in each subnetwork that connect the subnetwork to the Internet. For the home subnetwork, the HA functionality may be incorporated in the border router *R_h*. Similarly, for the foreign subnetwork, the gateway FA functionality that resides in FA1 may be integrated in the border router *R_v*. In hierarchical terms, the FA1 can act as a gateway FA. Otherwise, it acts as

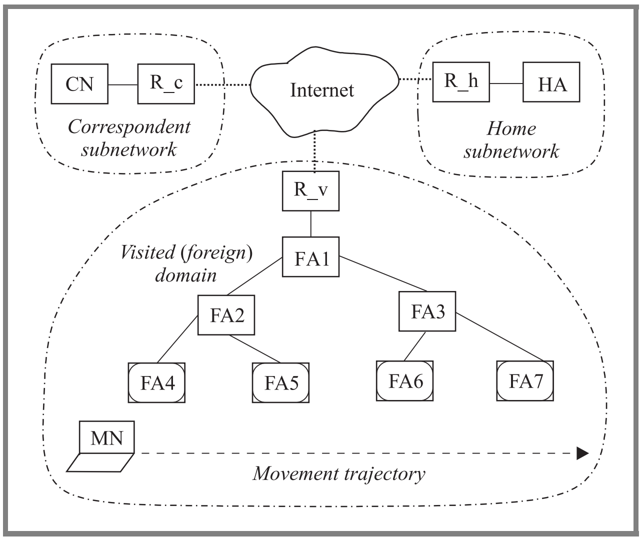

Fig. 4. Network topology used in the simulation.

a normal router or normal FA depending on the functionality implemented and the specific needs of the network. The FA hierarchy constructed this way may be used for the purpose of regional registration, or as a flat FA topology/structure in other cases. For FAs acting as leaf access routers (FA4 – FA7), it is assumed that the FAs have also been equipped with BS (base station, in 802.11 terms, access point) functionality. The coexistence of FA and BS functionalities in the same node also implies that any number of layer-2 handovers may occur as long as layer-3 IP address (a care-of address in mobile IP sense) has not been changed.

3.2. FA-HA path delay emulation

In order to emulate FA-HA path delay between the foreign subnetwork (in the visited domain) and the home subnetwork, we have set appropriately the “delay” attribute of the point-to-point link between the border router *R_v* and the Internet cloud. In the subsequent sections, we use *DD* to denote the FA-HA path delay between MN/FA and HA/CN. The combinations of nodes, like MN/FA and HA/CN, mean that we assume that MN moves typically around FA, and CN resides in the vicinity of HA, unless otherwise mentioned. The unit of *DD* is ms.

3.3. Wireless LAN configuration

WLAN is configured as IEEE 802.11, with 11 Mbit/s data rate and no RTS/CTS and fragmentation used. Each WLAN radio coverage is set to 250 metres; that ensures non-overlapping radio coverage of separate access points (BSs), eventually requiring a sort of hard handoff upon crossing the coverage boundaries.

3.4. Movement model

Mobility pattern of the MN is characterised by a horizontal linear path with constant ground speed of 30 km/h (the speed has been varied from 1 to 30 km/h when needed to observe the impact of moving speed on various performance measures). The moving speed (30 km/h) implies that MN moves faster than typical pedestrians but also slower than typical passenger vehicles in a metropolitan area. Consequently, this choice of mobility pattern results in a moderate handover rates.

3.5. Traffic model

The application traffic exchanged between the CN and MN is configured to represent either voice or data. For real-time voice traffic running on top of UDP transport protocol, we have configured it as IP telephony using voice over IP techniques where CN and MN act as clients to each other. The voice traffic exchanged between the MN and CN can start and stop in each direction in random manner, and continue until simulation stops. Unless otherwise mentioned in the relevant sections, almost all simulation results for this chapter are obtained using IP telephony voice traffic as the application traffic type. For data traffic using TCP transport protocol, we have used Ftp application (file download). Acting as client, MN requests a download of a data file from CN which is acting as a file server.

4. Simulation results

4.1. Definition of user/network satisfaction index

We define a new performance metric that is used for the evaluation of user satisfaction level. We call it user satisfaction index (USI) and use it to compare the performance of the adaptive handover control against non-adaptive handover methods.

The USI is denoted by $\mathscr{U}$. In general, $\mathscr{U}$ is defined as follows:

$$\mathscr{U} = \omega_1\mathscr{A}_1 + \omega_2\mathscr{A}_2 + \ldots + \omega_n\mathscr{A}_n = \sum_{i=1}^{m} \omega_i\mathscr{A}_i\,, \qquad (1)$$

where m is the number of application scenarios used to compute $\mathscr{U}$ and ω_i is the weighting factor for each application scenario i:

$$0 \le \omega_i \le 1, \qquad \sum_{i=1}^{m} \omega_i = 1 \qquad (2)$$

Table 1
Comparison of user and network satisfaction indices for handover strategies

Handover strategy		Voice (IP telephony)				Ftp data	
		DD = 0	DD = 100	DD = 200	DD = 300	DD = 0	$\mathscr{U}$, $\mathscr{N}$
NBa	USI_A	9.730	5.668	8.470	4.622	7.207	7.139
	NSI_A	10.000	10.000	10.000	10.000	10.000	10.000
NBu	USI_A	6.072	7.578	6.647	7.114	9.698	7.421
	NSI_A	9.994	9.995	9.996	9.995	9.988	9.993
NBi	USI_A	8.570	6.374	8.616	8.811	9.981	8.470
	NSI_A	9.979	9.979	9.979	9.980	9.979	9.979
RBa	USI_A	9.622	6.605	9.495	7.882	N/A	8.401
	NSI_A	7.504	7.503	7.504	7.502	N/A	7.503
RBu	USI_A	4.009	6.463	7.868	7.941	9.997	7.255
	NSI_A	7.500	7.501	7.500	7.500	7.497	7.499
RBi	USI_A	9.946	9.778	6.431	6.156	9.997	8.461
	NSI_A	7.493	7.493	7.490	7.493	7.494	7.492
AHC	USI_A	9.730	9.778	9.495	7.882	9.981	9.373
	NSI_A	10.000	7.493	7.504	7.502	9.979	8.495

$\mathscr{A}$ for a specific type of user application scenario[1] is defined as:

$$\mathscr{A}_i = \alpha_{i1}\mathscr{S}_{i1} + \alpha_{i2}\mathscr{S}_{i2} + \ldots + \alpha_{in}\mathscr{S}_{in} = \sum_{j=1}^{n} \alpha_{ij}\mathscr{S}_{ij}, \quad (3)$$

where α_{ij} is the weighting factor for each performance metric j (e.g. packet loss, delay, jitter, …). The value of α_{ij} resides between 0 and 1, and the sum of α_{ij} for all j values should be 1:

$$0 \le \alpha_{ij} \le 1, \qquad \sum_{j=1}^{n} \alpha_{ij} = 1. \quad (4)$$

Score value for performance metric type j, $\mathscr{S}_{ij}$ (for a specific application scenario i) is defined as the fraction of performance achievement against pre-defined level of perfect performance for each performance metric i (e.g. packet loss, delay, jitter, …). The range of value should be between 0 and 10:

$$0 \le \mathscr{S}_{ij} \le 10. \quad (5)$$

From (3) – (5), we can easily derive the possible value range of $\mathscr{A}$ as follows:

$$0 \le \mathscr{A}_i \le 10. \quad (6)$$

From Eqs. (1) and (3), we can get the general form of USI, $\mathscr{U}$ in terms of scores of performance measures, $\mathscr{S}_{ij}$ as

$$\mathscr{U} = \sum_{i=1}^{m} \omega_i \Big(\sum_{j=1}^{n} \alpha_{ij}\mathscr{S}_{ij}\Big) = \sum_i \sum_j \omega_i \alpha_{ij} \mathscr{S}_{ij} \quad (7)$$

and from Eqs. (2) and (6) the possible value of $\mathscr{U}$ falls into the range of 0 to 10:

$$0 \le \mathscr{U} \le 10. \quad (8)$$

To show how to use the USI performance metric, we give an example definition of user satisfaction index for "voice over IP" application traffic type as follows:

$$\begin{aligned}\mathscr{A}_{voip} = 0.4 * \mathscr{S}_{delay} + 0.4 * \mathscr{S}_{jitter} + \\ 0.1 * \mathscr{S}_{loss} + 0.1 * \mathscr{S}_{thru}\,.\end{aligned} \quad (9)$$

While the USI is oriented towards satisfaction level from the user's perspective, another metrics, the network satisfaction index (NSI), focuses on the satisfaction level from the network perspective.

The NSI can be thought of as a kind of *cost function*, which defines necessary cost for the use of network resources to manage operation of specific mobility mechanism. The computed value of NSI increases as the total cost of using network resources (the value of cost function) decreases.

One possible candidate of network resources to be accounted for in the NSI is available network bandwidth, normally shared among many users and thus valuable, especially in the bandwidth-limited wireless network environment. To measure the efficiency of network bandwidth usage, we express it as *signalling overhead*. The signalling includes control messages that are exchanged in the course of performing various mobile IP operations.

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[1] A user application scenario may be constructed to account for many factors, such as specific type of application traffic, end-to-end transmission delay etc.

Similarly to the definition of USI, $\mathscr{U}$ in Eq. (1), we can define NSI, $\mathscr{N}$ as follows:

$$\mathscr{N} = \omega_1\mathscr{A}_1 + \omega_2\mathscr{A}_2 + \ldots + \omega_n\mathscr{A}_n = \sum_{i=1}^{m} \omega_i\mathscr{A}_i\,, \qquad (10)$$

where m is the number of application scenarios used to compute $\mathscr{N}$ and ω_i is the weighting factor for each application scenario i. The weighting factor ω_i and the definition of $\mathscr{A}$, which is network satisfaction index specific to an application scenario, can be reused as defined in Eqs. (2) and (3) respectively.

Similarly to Eq. (8), the possible range of values for $\mathscr{N}$ is as follows:

$$0 \le \mathscr{N} \le 10\,. \qquad (11)$$

4.2. Comparison of handover strategies using satisfaction indices

In this section, we illustrate the benefits of adaptive handover control against various non-adaptive handover strategies. To compare the mechanisms, we have calculated USI and NSI values for the simulation results obtained for both voice traffic and Ftp data traffic.

Throughout the rest of this section we use following notation to distinguish between the different handover strategies used in the simulations:

NBa – basic mobile IP handover,
NBu – mobile IP handover with buffering,
NBi – mobile IP handover with pre-registration and bicasting,
RBa – mobile IP handover with regional registration,
RBu – mobile IP handover with regional registration and buffering,
RBi – mobile IP handover with regional registration, pre-registration and bicasting.

Table 1 summarises USI and NSI values calculated for each handover strategy including AHC. We have used notations USI_A and NSI_A to indicate $\mathscr{A}$ of USI and $\mathscr{A}$ of NSI respectively for each scenario case. The calculation of user satisfaction index $\mathscr{U}$ and network satisfaction index $\mathscr{N}$ based on Eqs. (1) and (10) respectively is carried with weighting factor $\omega_i = 1/m$ assuming that each application scenario contributes equal amount to the overall satisfaction of user or network. If we assume differently, i.e. modify the contribution factors for the scenarios of choice, we may get results for $\mathscr{U}$ and $\mathscr{N}$ different from those in Table 1. From the values of $\mathscr{U}$ and $\mathscr{N}$ as in Table 1, we can conclude that AHC outperforms the other, non-adaptive handover strategies at least in respect to user satisfaction index. In respect to network satisfaction index, the AHC shows better results than handover strategies using regional registration (i.e. RBa, RBu, and RBi). However, it becomes worse than handover strategies not using regional registration (NBa, NBu, and NBi) due to additional control overhead contributed by chosen handover strategies in certain scenarios. If the network satisfaction index is our main concern (e.g. within policy framework favouring the network operator's perspective), we may obtain better values for $\mathscr{N}$ by changing the handover adaptation algorithm to select handover strategies optimised for minimum use of network resources rather than for maximum user-perceived performance.

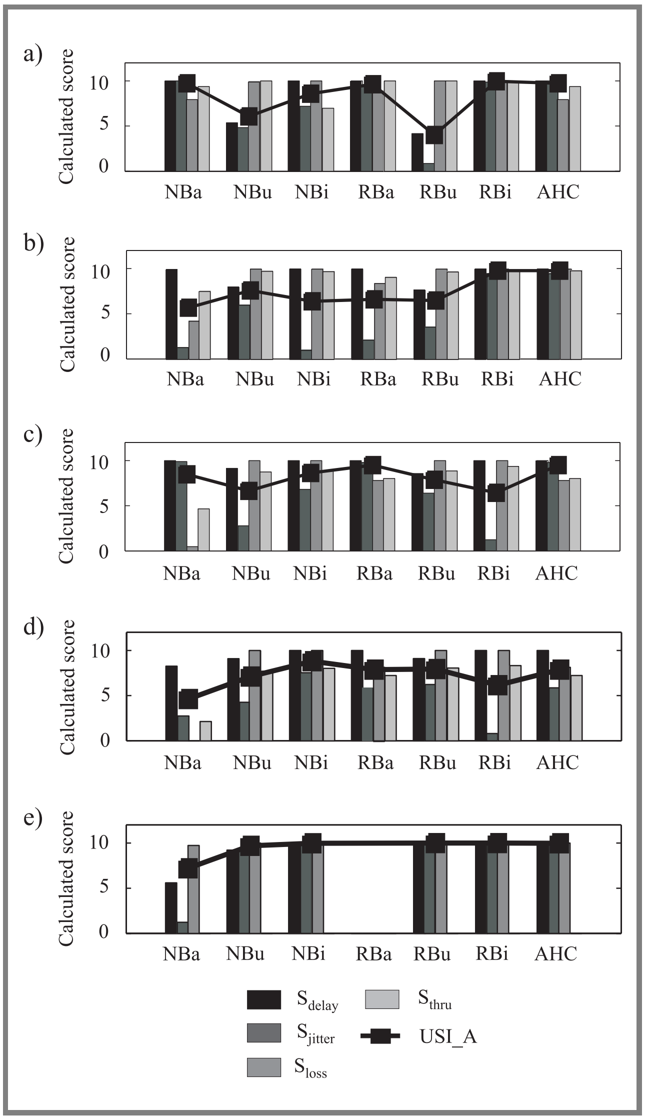

Fig. 5. Comparison of user satisfaction index for each scenario: (a) scenario 1 (VoIP, DD = 0 ms); (b) scenario 2 (VoIP, DD = 100 ms); (c) scenario 3 (VoIP, DD = 200 ms); (d) scenario 4 (VoIP, DD = 300 ms); (e) scenario 5 (Ftp, DD = 0 ms).

Using data in Table 1, we have compared user satisfaction index of $\mathscr{A}$ across all application scenarios in Fig. 5. In the figure, we have illustrated comparison of the value of $\mathscr{A}$ calculated for each simulated handover strategy. The histograms in each figure represent the score values of selected performance measures, which are then used for the calculation of corresponding $\mathscr{A}$ value for each handover strategy. For scenario 5, which uses Ftp data traffic type and the network topology with delay (distance) measure $DD = 0$, we could not get satisfactory results for the RBa handover strategy. Thus, we have considered only four application scenarios to calculate the value of $\mathscr{U}$ for the RBa handover strategy. As expected, the simulation results shown in the figure confirm that one handover strategy cannot fit all scenarios. In other words, we need to select handover strategy specific to each application scenario, case by case, to maximise user satisfaction level across all cases. This justifies the need for adaptive handover control proposed in this article.

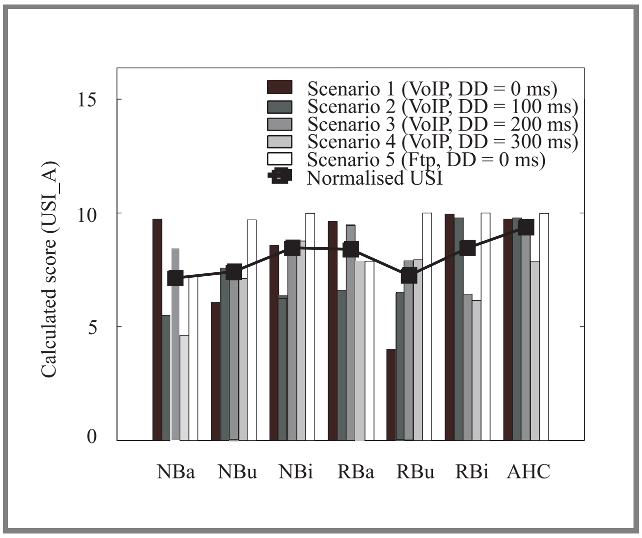

Fig. 6. Comparison of user satisfaction index over all the scenarios.

Figure 6 shows the comparison of user satisfaction index for various handover strategies, including the AHC proposed in this article. The values of $\mathscr{U}$ are obtained so as to cover all five handover scenarios (except the RBa case) with equal weighting factors for all scenarios. The AHC can be seen as outperforming the non-adaptive handover control cases. When we use the score functions as defined in Section 4.1, the estimated increase in user satisfaction index attributed to the use of AHC is about 31.3% measured against the worst-performing NBa, and about 10.7% measured against the best performing fixed handover strategy NBi.

5. Conclusions

While mobile IP protocol is generally considered to be a reasonable solution for mobility across IP subnetworks, many works available in the subject literature indicate that mobile IP alone (as specified by IETF) is not sufficient to provide seamless IP mobility, especially for time-critical (real-time or delay-sensitive) applications. The same argument can be applied to applications with other QoS attributes.

Inspired by the realisation that one solution can not suit all situations equally well, we have proposed a smart handover control framework, called the AHCA. The AHCA was designed to be flexible and open to changes of the design details such as the number of inputs and the specific handover adaptation algorithm. The component modules of the architecture can be freely substituted or modified as desired depending on the network operating conditions and characteristics of the application services and network users.

The possible extension of the AHCA could be the incorporation of modern control theory into some component modules of the architecture, as well as dynamic policy-based handover control. The implementability of the AHCA has been already confirmed through detailed functional specifications of its component modules and interfaces between them. Both qualitative and quantitative study of the benefits from using AHCA as compared to non-adaptive handover strategies is currently in progress. This extensive simulation study involves multiple network and user scenarios, as well as multiple component mechanisms of the adaptive handover.

Acknowledgements

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References

[1] H. Chaskar, Ed., “Requirements of a QoS solution for mobile IP”, Draft-ietf-mobileip-qos-requirements-01.txt, work in progress, Aug. 2001.

[2] K. Ishibashi, K. Shimizu, and S. Seno, “Behavior of a mobility agent in mobile IP in order to manage the flow”, Draft-ishi-mobileip-behavior-ma-00.txt, work in progress, Oct. 2001.

[3] D. B. Johnson and D. A. Maltz, “Protocols for adaptive wireless and mobile networking”, *IEEE Pers. Commun.*, vol. 3, no. 1, pp. 34–42, 1996.

[4] M. E. Kounavis, A. T. Campbell, G. Ito, and G. Bianchi, “Design, implementation and evaluation of programmable handoff in mobile networks”, *Mob. Netw. Appl.*, vol. 6, no. 5, pp. 443–461, 2001.

[5] K. Lee, “Adaptive network support for mobile multimedia”, in *Proc. First Ann. Int. Conf. Mob. Comput. Netw. (MOBICOM 95)*, Berkeley, USA, Nov. 1995, pp. 62–74.

[6] R. R.-F. Liao and A. T. Campbell, “A utility-based approach for quantitative adaptation in wireless packet networks”, *Wir. Netw.*, vol. 7, no. 5, pp. 541–557, 2001.

[7] Ch. Lu, T. F. Abdelzaher, J. A. Stankovic, and S. H. Son, “A feedback control approach for guaranteeing relative delays in web servers”, *IEEE Real-Time Technol. Appl. Symp.*, TaiPei, Taiwan, June 2001.

[8] MIPv4 handoffs design team, "Low latency handoffs in mobile IPv4", Draft-ietf-mobileip-lowlatency-handoffs-v4-03.txt, work in progress, Nov. 2001.

[9] T. Park, "Seamless handoffs in heterogeneous wireless network environments", in *Proc. CRCSS Conf. 2001*, Newcastle, Australia, Feb. 2001, p. 53.

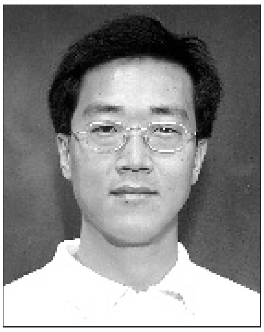
[10] T. Park and A. Dadej, "Adaptive handover between terrestrial and satellite wireless networks", in *Proc. CRCSS Conf. 2002*, Canberra, Australia, Feb. 2002, p. 46.

[11] C. Perkins, Ed., "IP mobility support for IPv4", RFC 3344, Aug. 2002.

[12] J. Solomon, *Mobile IP: The Internet Unplugged*. Englewood Cliffs: Prentice Hall, 1998.

[13] M. Stemm and R. H. Katz, "Vertical handoffs in wireless overlay networks", *Mob. Netw. Appl.*, vol. 3, no. 4, pp. 335–350, 1998.

[14] H. J. Wang, R. H. Katz, and J. Giese, "Policy-enabled handoffs across heterogeneous wireless networks", in *Proc. WMCSA'99*, New Orleans, Louisiana, Feb. 1999.



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