Adaptive Traffic Dependent Fuzzy-based Vertical Handover for Wireless Mobile Networks

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***Abstract*—An intelligent handover decision system is necessary for heterogeneous wireless mobile networks to fulfill user's expectations in terms of the quality of services. With emerging real-time services, including multiple QoS parameters in handover decision process seems essential. In this paper, fuzzy logic is applied to enhance the intelligence of the handover decision engine. An adaptive traffic dependent fuzzy-based handover decision system (ATD-HDS), which employs multiple decision engines each optimized to a specific traffic type, is presented. The results show that, compared to a monolithic fuzzy-based handover decision system, the proposed ATD-HDS significantly improves the decision quality and algorithm execution time.**

***Keywords*-fuzzy logic; handover; traffic dependent; adaptive; wireless; heterogeneous**

I. INTRODUCTION

Heterogeneous wireless mobile networks require interconnections of diverse wireless technologies such as WLAN, WiMAX and Cellular mobile networks as illustrated in Fig. 1. Mobile users expect seamless services over a wide area of mobility, with adequate quality and favourable price. In order to satisfy the above requirements, multiple handovers often become necessary. A handover may take place in a homogeneous network environment (horizontal handover) or in a heterogeneous network environment (vertical handover). In either case some form of decision mechanism needs to exit within the mobile device.

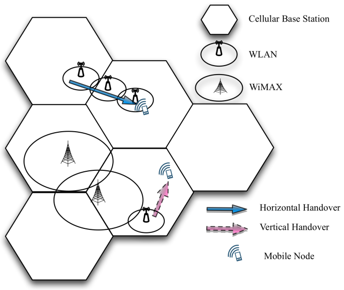

Fig. 1. Architecture of Heterogeneous Wireless Networks

A horizontal handover decision [1] is normally a straightforward process as the decision can simply be based on the received signal strength (RSS). However, due to varied characteristics of different wireless networks, a simple RSS based decision cannot achieve the required results in a vertical handover decision process. Clearly there is a need for a much more intelligent handover decision system (HDS) in heterogeneous network environment [2].

Numerous fuzzy logic based solutions, which enhance intelligence for vertical handovers, have been presented in the literature [3], [4]. However, in most of the existing work only a limited number of decision parameters are considered. This restriction seems to be due to the fact that as the number of decision parameters increases, the number of fuzzy rules increases significantly, which leads to computational complexity and very long execution time.

Nevertheless, for a more realistic evaluation of a vertical HDS, an increased number of decision parameters must be considered. Furthermore, due to the growing demand for real-time services (VoIP, video streaming, etc.), the decision parameters concerned with the QoS requirements (latency, jitter and packet loss) are an essential part of this work.

In this paper, we are presenting an adaptive traffic dependent fuzzy-based HDS. The HDS consists of three dedicated decision engines; each optimized to a given traffic stream. The traffic streams assumed are: Constant Bit Rate (CBR), Variable Bit Rate (VBR) and Available Bit Rate (ABR). The fact that each traffic type has different QoS requirements has been taken into account in the design of decision engines. In doing so, the total number of fuzzy rules have been reduced.

The performance of the proposed approach is compared, in terms of the decision quality and execution time, with a conventional monolithic fuzzy-based HDS design and Simple Additive Weighting (SAW). Simulation results show an improvement of over 39% in the handover performance and a reduction of up to 90% in algorithm execution time in certain scenarios.

The paper is organized as follows. The related work is presented in section 2. Section 3 presents a monolithic fuzzy-based HDS. In section 4, an adaptive traffic dependent fuzzy-based HDS is presented. Handover decision system designs are given in section 5. Section 6 gives simulation results and comparison between different HDS designs. Conclusions and future work is given in section 7.

II. RELATED WORK

As has been stated previously, numerous fuzzy-based solutions for vertical handover decision systems have been proposed in the literature. A fuzzy-based vertical handover decision algorithm, which assumes interconnection between WLAN and WMAN, is proposed in [5]. The decision parameters considered are: RSS, data rate, usage cost and user preference. The main aim of this work is to minimize the number of handovers and the results presented are encouraging.

In a more recent work [6], minimization of the number of handovers is considered whilst assuming RSS, data rate and usage cost as the primary decision parameters. The results show that the proposed algorithm can dramatically reduce the total number of handovers.

A fuzzy-based handover decision for interconnection between WLAN and WiMAX is proposed in [7]. The decision parameters considered are: RSS, data rate, and distance. The main aim of this work is to minimize the percentage packet loss, which is achieved successfully.

In all the above solutions, only the data rate is assumed to be the QoS related decision parameter. However, recognizing the importance of including other QoS parameters such as latency, jitter and packet loss in the decision process, a great deal of effort has been directed to evaluate the performance of a HDS in the presence of multiple QoS parameters.

In [8], [9], bit error rate (BER) and RSS are considered in their fuzzy-related decision algorithm. The results show improvement in terms of the number of handover reduction. In [10], a fuzzy-based vertical handover algorithm taking data rate, delay and BER (along with other parameters such as cost and security) into consideration is proposed. The algorithm improves the process of wireless network selection, thus avoiding unnecessary handovers.

Authors in [11] have proposed a QoS aware fuzzy rule based vertical handover mechanism that considers data rate, latency, jitter and BER. The proposed work is found to be effective for selecting a wireless network that meets the requirements of different applications. The results show a reduction in average end-to-end delay and yield a moderate average bandwidth.

It seems that although it is important to extend the number of decision parameters (which must include the QoS parameters), it is often not done due to computational complexity, which results in unacceptably long execution time. Thus, a new approach is needed that allows an extended number of decision parameters to be included, considers QoS and minimizes the execution time.

III. MONOLITHIC FUZZY-BASED HDS

A. Architecture of Fuzzy System

The architecture of a fuzzy system is shown in Fig. 2. It comprises four components. Fuzzifier converts crisp inputs into fuzzified data. Rule base contains IF-THEN rules, which are required by the Fuzzy Inference System (FIS). FIS generates aggregated fuzzified data, based on fuzzy inference method used. Defuzzifier converts the aggregated fuzzified data into a scalar value (score). The score is then used by the application.

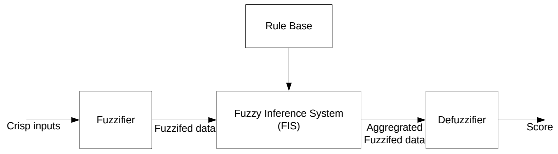

Fig. 2. Architecture of Fuzzy System

B. Development of Monolithic Fuzzy-based HDS

In this study we have taken six decision parameters: data rate (DR), usage price (PR), battery life (BA), latency (LA), jitter (JI) and packet loss (PL). The corresponding input fuzzy sets are denoted by $\widetilde{DR}$, $\widetilde{PR}$, $\widetilde{BA}$, $\widetilde{LA}$, $\widetilde{JI}$ and $\widetilde{PL}$.

Each fuzzy set has three fuzzy memberships (low, medium and high). With this combination the total number of rules = 3^6 = 729. Each rule is then assigned a decision output, which is based on expert knowledge. This process formulates an output fuzzy set, $\tilde{Z}$, which contains seven fuzzy memberships defined as: very low (VL), low (L), medium-low (ML), medium (M), medium-high (MH), high (H) and very high (VH)). Triangular functions are used to express the fuzzy memberships in both input and output fuzzy sets.

The crisp inputs (the values for each of the six parameters offered by the mobile node and individual wireless networks within heterogeneous network environment) are fuzzified and provided to FIS. There are two well-known fuzzy inference systems, namely, Mamdani [12] and Sugeno [13]. However, Mamdani FIS is used in this work as it is known to be well suited to capture expert knowledge [14].

The aggregated fuzzified data, $\mu\tilde{Z}_{mono}$, is given by:

$$\begin{aligned}\mu\tilde{Z}_{mono}(y) =& max_k[min[\mu\widetilde{DR}^k(datarate),\\ & \mu\widetilde{LA}^k(latency), \mu\widetilde{JI}^k(jitter),\\ & \mu\widetilde{PL}^k(packetloss), \mu\widetilde{PR}^k(price),\\ & \mu\widetilde{BA}^k(battery)]],\\ & fork = 1, 2, 3, \ldots, 729 \end{aligned} \tag{1}$$

where k is the total number of rules.

Defuzzifier then converts the aggregated fuzzified data into crisp value (score). The final score, $Score_{mono}$, is calculated using a centroid method given by:

$$Score_{mono} = \frac{\int \mu\tilde{Z}_{mono}(y).ydy}{\int \mu\tilde{Z}_{mono}(y)dy} \tag{2}$$

This score is then used to make the handover decision.

IV. ADAPTIVE TRAFFIC DEPENDENT FUZZY-BASED HDS

From the above work, we note that extending the number of decision parameters to six (with three memberships), a monolithic decision engine generates 729 rules. This raises the question of execution time. Furthermore, the membership functions used are fixed for all types of traffic streams.

In order to deal with the above two issues, we are proposing a new adaptive traffic dependent fuzzy-based HDS (ATD-HDS), in which multiple decision engines are employed, the number of rules is reduced by considering the QoS requirements [15] for each traffic type and the FMFs are tailored to match the characteristics of the incoming traffic.

The system consists of three dedicated fuzzy-based decision engines, each matched to one of the three traffic types, namely, CBR, VBR and ABR. The Engine Selector (ES) first identifies the traffic type and then selects the corresponding decision engine to carry out the network selection process. The general architecture is shown in Fig. 3

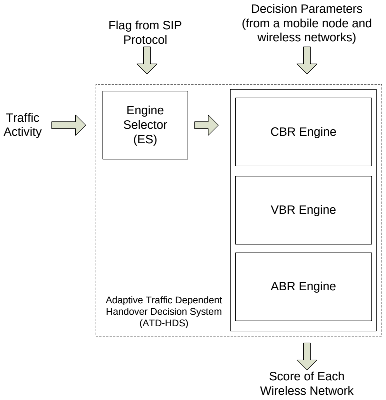

Fig. 3. Architecture of ATD-HDS

The ES periodically sniffs incoming packets with sufficient frequency to detect traffic activity. The traffic type is identified by receiving a flag from the application layer. This can be obtained from a commonly used session initiation protocol (SIP), which runs at the application layer. SIP has the ability to differentiate between CBR and VBR traffics. Thus, the ES selects one of the three engines using the following logic (as shown in Fig. 4):

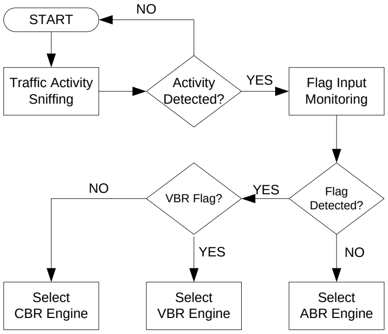

Fig. 4. Logic of Engine Selection

- Traffic activity is present and CBR flag is received - select CBR engine.
- Traffic activity is present and VBR flag is received - select VBR engine.
- Traffic activity is present but NO flag is received - select ABR engine

The number of rules is reduced by including latency, jitter and packet loss for CBR engine, latency and packet loss for the VBR engine and only packet loss for ABR decision engine. By this matching process the total number of rules becomes 729, 243 and 81 for CBR, VBR and ABR decision engines respectively.

The quality of decision is enhanced by using a combination of triangular and trapezoidal functions to express the fuzzy memberships. Furthermore, the fuzzy membership functions (FMFs) are tailored according to the QoS requirements of each traffic type.

V. HANDOVER DECISION SYSTEM DESIGNS

Three HDS designs are produced: Monolithic design 1 (MD1) , Monolithic design 2 (MD2) and ATD design.

MD1 is a conventional design with 6 decision parameters and all FMFs are triangular, with no regard to the incoming traffic type. MD2 has 6 decision parameters but the FMFs are a combination of triangular and trapezoidal functions, which are tailored to the most QoS-sensitive traffic (in Fig. 5).

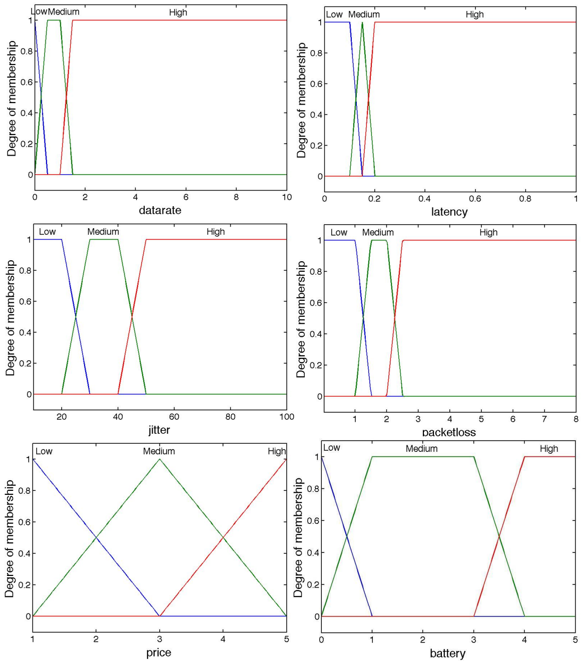

Fig. 5. FMFs Specific to CBR Traffic

ATD design has a variable number of decision parameters and employs a combination of triangular and trapezoidal functions, which are tailored to the incoming traffic, as shown in Fig. 5, 6 and 7 (noting that Fig. 5 is common to MD2 and ATD designs).

A small portion of the fuzzy rules for CBR traffic is given (in table I) to illustrate the general idea. As the number of decision parameters is fixed in MD1 and MD2, the same set of rules is used for all traffic types (CBR, VBR and ABR), and in all the three HDS designs. In contrast, the number of

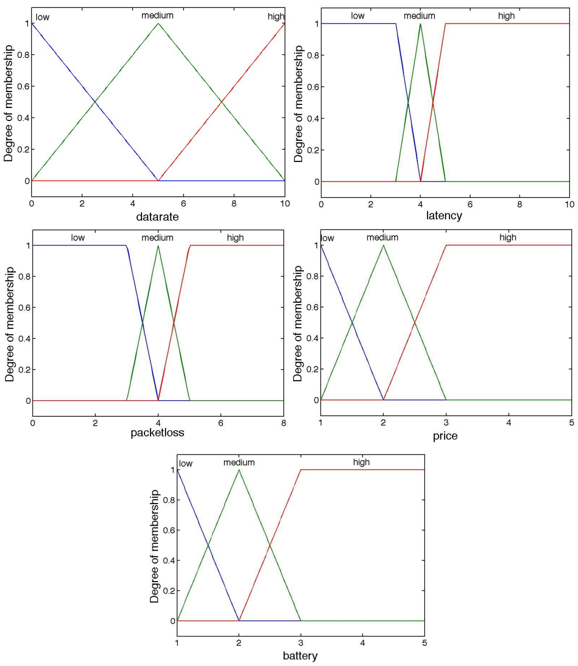

Fig. 6. FMFs Specific to VBR Traffic

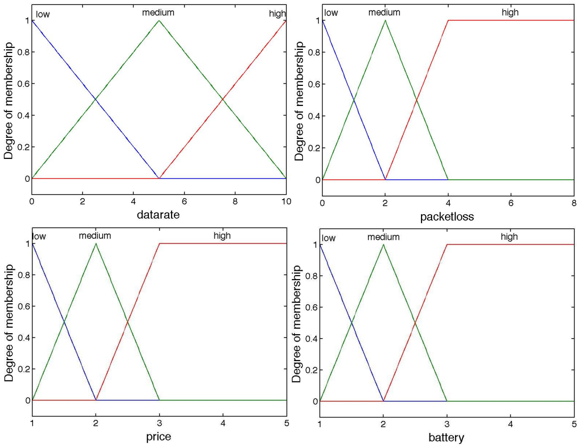

Fig. 7. FMFs Specific to ABR Traffic

decision parameters is variable in ATD design, so different sets of rules are used for different traffic types, as can be seen from tables I

VI. RESULTS AND DISCUSSION

To evaluate handover decision performance of the three fuzzy-based HDS designs, we have assumed three wireless network technologies (WLAN, WiMAX and Cellular) and three traffic models (VoIP, video streaming and file transfer). Their QoS requirements are given in [15]

The performance criteria are the percentage success, which is measured in terms of the number of times (expressed as a percentage) the HDS selected the wireless network that had the highest score among the three and fully satisfied the QoS requirements, and the execution time.

TABLE I
FUZZY RULES FOR EACH INDIVIDUAL TRAFFIC TYPE

Fuzzy Rules for CBR Traffic							
No.	DR	LA	JI	PL	PR	BA	Output
1	Low	Low	Low	Low	Low	Low	M
2	Low	Low	Low	Low	Low	Medium	MH
:	:	:	:	:	:	:	:
729	High	High	High	High	High	High	ML
Fuzzy Rules for VBR Traffic							
No.	DR	LA	JI	PL	PR	BA	Output
1	Low	Low	▨	Low	Low	Low	ML
2	Low	Low	▨	Low	Low	Medium	M
:	:	:	▨	:	:	:	:
243	High	High	▨	High	High	High	VL
Fuzzy Rules for ABR Traffic							
No.	DR	LA	JI	PL	PR	BA	Output
1	Low	▨	▨	Low	Low	Low	ML
2	Low	▨	▨	Low	Low	Medium	M
:	:	▨	▨	:	:	:	:
81	High	▨	▨	High	High	High	ML

A. Performance Measurement

Crisp input value for each of the decision parameters (with the exception of usage price) is randomly selected from the range given in table II, and used in all the three HDS designs in the case of VoIP traffic.

Similarly, in the case of video streaming, crisp values are randomly selected from table III and used in ATD, whereas MD1 and MD2 also need a value for jitter (JI), which is taken from table II.

In the case of file transfer traffic, crisp values are randomly selected from table IV and used in ATD. JI is taken from table II and used in MD1 and MD2, and latency (LA) is taken from table III and used in MD1 and MD2.

The usage price for individual technologies is set at a fixed value and assumed to be incremental (i.e. WLAN to be least expensive and Cellular to be most expensive [16]).

The range of values for decision parameters in tables II, III and IV are taken either from real-life tests or commonly used standards [17]–[21].

TABLE II
DECISION PARAMETERS FOR CBR TRAFFIC

Network	DR (Mbps)	LA (ms)	JI (ms)	PL (%)	BA (hrs)	PR (p/min)
WLAN	1 - 8	0-300	0-50	0-1.5	2.5 - 5	1
WiMAX	3 - 6				0.55x(2.5-5)	2
Cellular	1 - 5				0.74x(2.5-5)	3

TABLE III
DECISION PARAMETERS FOR VBR TRAFFIC

Network	DR (Mbps)	LA (s)	JI (ms)	PL (%)	BA (hrs)	PR (p/min)
WLAN	1 - 8	0-7	▨	0-7	2.5 - 5	1
WiMAX	3 - 6				0.55x(2.5-5)	2
Cellular	1 - 5				0.74x(2.5-5)	3

The three HDS designs are simulated using Fuzzy Logic tool on MATLAB platform. Each of the three HDS designs is evaluated by running the algorithm for 200 times for each

TABLE IV
DECISION PARAMETERS FOR ABR TRAFFIC

Network	DR (Mbps)	LA (s)	JI (ms)	PL (%)	BA (hrs)	PR (p/min)
WLAN	1 - 8			0-7	2.5 - 5	1
WiMAX	3 - 6				0.55x(2.5-5)	2
Cellular	1 - 5				0.74x(2.5-5)	3

traffic type. The above procedure was repeated to evaluate the performance of Simple Additive Weighting (SAW) for a comparison purpose. Simulation results are shown in Fig. 8, 9 and 10.

In the case of VoIP traffic (Fig. 8), the performance of MD2 and ATD design have exactly the same performance. This result is expected as identical rules and FMFs are employed. However, there is an improvement of 37.4% compared with MD1, which employs the same rules but fixed FMFs, and an improvement of 38.78% when compared with SAW.

It is interesting to note in Fig. 9 that the performance of MD2 is slightly worse than MD1, in the case of video streaming traffic. As FMFs in MD2 are tailored for the most QoS-sensitive traffic, relatively less QoS-sensitive traffic is penalized. The performance of ATD design, on the other hand, is 24.17%, 22.03% and 30.58% better than SAW, MD1 and MD2, respectively.

In the case of file transfer traffic, Fig. 10, a similar picture emerges when comparing the performance of MD1 and MD2. However, the performance of ATD is comparable with MD1 and is slightly better than SAW. This result suggests that the tailoring of FMFs is more beneficial when the number of QoS parameters is increased.

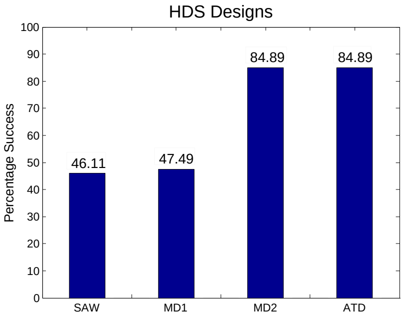

Fig. 8. Network Selection Performance - VoIP

B. Algorithm Execution Time

As has been mentioned in section 1, minimization of the execution time (τ) is an essential requirement for real-time applications. We have evaluated τ for the three HDS designs and SAW. The evaluation was carried out on a 2.13GHz Intel Core 2 Duo with 4GB memory.

The results in Fig. 11 clearly show that our proposed ATD design significantly reduces τ for relatively less QoS-sensitive traffics. The reduction achieved in τ is 70.05% and 90.37% for video streaming and file transfer traffic, respectively. However, in the case of VoIP, there is no significant reduction in the value of τ. It is to be expected as all the three HDS designs employ the same number of decision parameters. The execution time of SAW is lower than that of ATD.

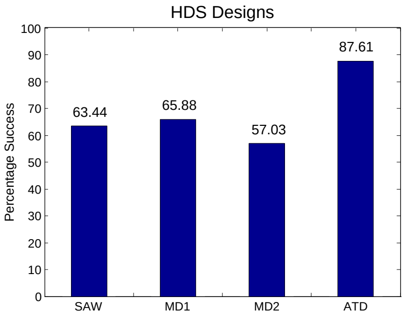

Fig. 9. Network Selection Performance - Video Streaming

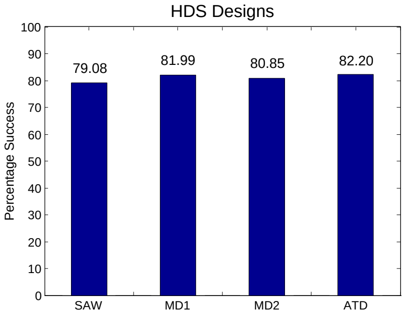

Fig. 10. Network Selection Performance - FTP

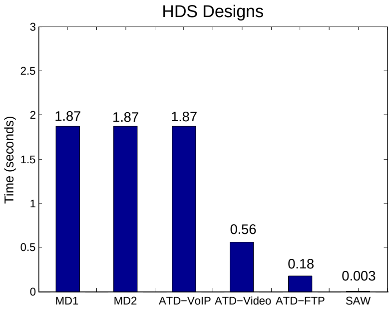

Fig. 11. Algorithm Execution Time

C. Battery Consumption Analysis

Our comparison of fuzzy-based algorithms with SAW algorithm reveals that the superiority of fuzzy-based designs comes at a price, i.e. the algorithm execution time of even the best (ATD) fuzzy algorithm is much higher than that required by the SAW. This raises the issue of power consumption and the recharging frequency for the battery. In order to address these issues we have made some projections based on the data available to us.

Our simulations were carried out on MATLAB platform using Intel processor of 65watts rating. The longest execution time (worst case) for our fuzzy algorithms is 1.87 seconds (Fig. 11). Therefore, the power consumption for the worst case = 65x1.87 = 121.55 watt-seconds or 0.033 watt-hours. Now the battery capacity of a modern smart phone is around 5.5 watt-hour. Thus, a smart phone can execute the above algorithm around 166 times (this does not include the power consumption of other components) before the battery needs recharging.

If we now consider a processor that is actually used in mobile devices (e.g. ARM Cortex A series of 1.3 watts rating), the estimated power consumption reduces to 0.000675 watt-hour. Assuming the same battery as above, a smart phone can execute the algorithm for over 8,000 times before the need for recharging. Further improvements will come from the fact that an actual mobile device is likely to use dedicated and embedded software instead of MATLAB platform to run fuzzy algorithm. This will further reduce execution time and hence the power consumption.

VII. CONCLUSIONS AND FUTURE WORK

We have proposed an adaptive traffic dependent handover decision system to deal with the restriction imposed on the number of decision parameters mainly due to the fact that as the number of decision parameters increases, the number of fuzzy rules increases to a very large value, resulting in computational complexity and an unacceptably long execution time. In our approach multiple decision engines, each optimized to a specific traffic type, have been suggested. The optimization has been achieved by tailoring FMFs to match the QoS requirements of each individual traffic type. The number of fuzzy rules has been reduced, compared with a conventional monolithic decision engine, by including only those QoS parameters that are essential for a given traffic type.

For evaluation and comparison purposes, three handover decision system designs (Monolithic design 1, Monolithic design 2 and ATD) have been developed. Assuming a heterogeneous networking environment and three traffic types (VoIP, video streaming and file transfer), simulation results have been produced to compare the performance of the three HDS designs and SAW in term of the decision quality and execution time.

In terms of the decision quality, the simulation results show that ATD design gives an improvement of 37.4% and 22.03% for VoIP and video streaming traffics respectively, when compared with Monolithic design 1. The performance of ATD is comparable with others in the case of file transfer traffic.

In terms of the execution time, the results show that ATD design gives an improvement of over 90% and 70% in case of file transfer and video streaming traffics respectively, when compared with Monolithic design. The performance of Monolithic and ATD designs is comparable in the case of VoIP traffic. Battery consumption analysis suggests that the power consumption of the proposed algorithm is unlikely to have a major impact on the battery life in real-life implementation.

Future work will investigate possibilities of further reduction in computational complexity and hence execution time for the handover process.

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