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A Multimetric Approach for Handoff Decision in Heterogeneous Wireless Networks

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Abstract. Seamless mobility and service continuity anywhere at any time are an important issue in the wireless Internet. This research proposes a scheme to make handoff decisions effectively in heterogeneous wireless networks using a fuzzy system. Our design lies in an inference engine which takes RSS (received signal strength), data rate, network latency, and user preference as strategic determinants. The logic of our engine is realized on a UE (user equipment) side in faster reaction to network dynamics while roaming across different radio access technologies. The fuzzy system handles four metrics jointly to deduce a moderate decision about when to initiate handoff. The performance of our design is evaluated by simulating move-out mobility scenarios. Simulation results show that our scheme outperforms other approaches in terms of reducing unnecessary handoff.

1. Introduction
Next generation wireless networks (NGWN) enables a mobile user to roam with a UE (user equipment) with multiple interfaces to access real time or non-real time services. Multi-radio operations in a heterogeneous environment are becoming a norm. The fourth generation (4G) of mobile broadband technology has implemented the integration of multiple networks such as wireless Local Area Networks and mobile telecommunications networks on an all-Internet Protocol basis for broadband mobile capacities. System heterogeneity offers a variety of services and applications with significantly higher data rates anytime and anywhere. However, the Always Best Connected concept allowing seamless mobility and service continuity anywhere at any time is still one of key challenges in such an environment [1]. As NGWN is aimed at ubiquitous computation and communication, the UE should enjoy seamless data transfers via the best access link among all available candidates without perceivable interruption to streaming services [2].

Handoff decision is to select the best prospective access network in the vicinity and decide at any given time whether or not to carry out handoff. Traditional or horizontal handoff involves processing between two adjacent cells of the same radio access technology. Certain link quality parameters such as RSSs (received signal strengths) or signal-to-noise ratios are commonly considered in handoff management. If concerned parameters fall below a predefined threshold, handoff is initiated. Due to different protocol structures and parameters present in the heterogeneous environment, the horizontal handoff mechanism does not cater well for such a networking environment [3].

On the other hand, handoffs among different radio access technologies occur frequently when a mobile user roams about. In particular, handoff involving switching among different types of wireless
network is referred to as vertical handoff [4]. Vertical handoff decision warrants closer study. A number of schemes for handoff decision making solutions exist in the literature, that is, solutions based on network conditions using the received signal strength (RSS) or the signal-to-interference-and-noise ratio measured by mobile node, multi attribute decision making algorithms to improve the quality of services, and artificial intelligence using fuzzy logic and neural networks.

The first strategy is based on network conditions using RSSs measured by the UE. Effects of the signal strength threshold combined with an adaptive lifetime metric, available bandwidth, and packet delay has been investigated in [5]. A cross-layer management protocol proposed in [6] uses the speed of the UE and handoff signaling delay information to enhance handoff performance. A layer-3 handoff process is initiated if the RSS of the current base station has dropped below some threshold. However, only RSS alone was evaluated as a metric for considering handoff decision in these schemes.

The second strategy uses a mathematical optimization technique that deals with the problem of choosing the best alternative from a set of options based on their attributes. A performance comparison among vertical handoff algorithms, namely, MEW (multiplicative exponent weighting), SAW (simple additive weighting), TOPSIS (technique for order preference by similarity to ideal solution), and GRA (gray relational analysis) has been proposed in [7]. Comparative results show that MEW, SAW, and TOPSIS provide similar performance irrespective of different traffic classes, while GRA provides a slightly higher bandwidth and a lower delay for interactive and background traffic classes. Network selection in vertical handoff decision, as indicated in [8], can be carried out by using the Multiple Attribute Decision Making strategy. However, this study proposes a handoff mechanism in use by the UE with limited computing powers and resources constraints.

The third strategy refers to artificial intelligence techniques through a fuzzy logic or neural networks combined with several metrics such as network conditions [9], [10]. These approaches consider various input parameters as handoff decision criteria. Provided that RSS is one of the most common metrics accessible to the UE, we still ponder RSS as a determinant to trigger a handoff process. Additionally, in view that a tradeoff among other measures is required for making a vertical handoff decision, we fuse RSSs, data rate, network latency, and user preference that will be taken as multi-criteria inputs to a fuzzy system for reasoning out a single-valued output, indicating whether vertical handoff is imminent.

Our design is indeed complementary to previous studies in that our work can strengthen their operational efficiency. The remainder of this paper is organized as follows. The next section elaborates on related work. Our scheme is provided in Section 2. Section 3 discusses performance results. Lastly, Section 4 draws conclusions.

2. Vertical Handoff Strategy

Under consideration is a two-tier communication paradigm where IEEE 802.11 connectivity is preferred over the cellular network. Accordingly, we are concentrating on WLAN accessibility first. In our architecture, handoff to the cellular network may occur if IEEE 802.11 connectivity cannot sustain.

Handoff decision controller as a decision engine is performed by a fuzzy system. The general architecture of a fuzzy system consists of a fuzzifier, knowledge base IF-THEN rules, fuzzy inference engine, and a defuzzifier [11] as illustrated in Figure 1. In our architecture, each of the input parameters is assigned to one of three fuzzy sets. Values for each type of input consist of linguistic terms: weak, medium, and strong for the RSS parameter; low, medium, and high for the remaining three metrics. These sets are mapped to corresponding membership functions (MF) which refer to characteristic functions defining the fuzzy set as depicted in Figure 2. The general MFs are triangular, trapezoidal, Gaussian, bell, and sigmoidal shapes. The MFs can be chosen arbitrarily according to the user’s experience [12]. Here we chose trapezoidal MFs, because this kind of MFs is most frequently used in practical applications [13]. The ranges of inputs for each fuzzy variable RSS, data rate, latency, and user preference are shown in Table 1.
The rule base contains IF-THEN rules which are required by the Fuzzy Inference System (FIS). Among all possible inference systems, we implement the Mamdani FIS in that it is intuitive, widely accepted and operates in line with human instinct. The database defines membership functions of the fuzzy sets. FIS generates aggregate fuzzified data, based on fuzzy inference methods. The defuzzifier converts the aggregate fuzzified data into a scalar value. The output fuzzy decision sets are aggregated into a single fuzzy set and passed to the defuzzifier to be converted into a precise quantity, the handoff factor, which determines whether a handoff is necessary. We design four fuzzy input variables and three fuzzy sets for each fuzzy variable, so the maximum possible number of rules in our rule base is $3^4 = 81$. The crisp output from the defuzzifier block is used to select the most appropriate network for...
the UE. The universe of discourse for the handoff factor variable ranges from 0 to 10 as shown in Figure 3.

Figure 3. Membership function of the handoff factor.

When the UE is departing from an AP, this is referred to as a move-out scenario, where the UE is expected to perform a vertical handoff to the cellular network soon. On the contrary, if the UE is associating to an AP from the cellular network, a move-in scenario happens, during which another vertical handoff shall occur shortly. In this study, handoff decision is made in a move-out scenario as the following lines:

- If the deduced handoff factor is greater than or equal to 6, then the UE selects the cellular network.
- If the handoff factor is less than 6, then the UE stays connected with its current access network.

The handoff process is diagramed in Figure 4. First, a UE constantly monitors RSSs of a serving point of attachment to the system, either an AP or a base station, and other three parameters to be processed by the FIS. After knowing that the move-out scenario of the UE is determined, the output of the FIS will indicate whether the UE should initiate a vertical handoff or stay connected with the current network.

3. Performance Evaluation

In order to compare our approach with other schemes, we conducted experiments over MATLAB by simulating the network paradigm illustrated in Figure 5. Parameters in use by simulation models are listed in Table 2. $\beta$, $\varepsilon$, $x_0$ are the path loss exponent, a zero-mean Gaussian random variable with standard deviation $\sigma$, and a reference distance, respectively for path loss model. Meanwhile $Q$ and $R$ are the covariance of the process and measurement noise for the Kalman filter parameters.

We assume that the UE behaves under the mobile-controlled handoff (MCHO) strategy. In this strategy, a UE periodically monitors the signal of an AP and initiates handoff when certain criteria are satisfied. Suppose that the UE moves away rectilinearly from APs A towards B. The two APs are geographically dispersed, with disjoint coverages overlaid on the cellular network. The trajectory stretches 1000 meters. We shall examine how our schemes perform when the UE experiences move-out scenario.
Next we focus on how many handoffs are initiated during simulations. In the move-out scenario, the UE performs 75, 55, and 18 vertical handoffs with the traditional fixed-RSS [6], Kalman-filtered RSS [14], and our design, respectively (Figure 6). From Figure 6, it can be seen that the last two approaches reduce handoffs considerably in comparison to the traditional one, with relative reductions reaching 26.67% and 76%, respectively. Relative reductions are assessed below:

$$\frac{(75 - 55)}{75} \times 100 = 26.67\%$$

$$\frac{75 - 18}{75} \times 100 = 76\%$$

### Table 2. Simulation parameters.

| Parameter | Value | Parameter | Value |
|-----------|-------|-----------|-------|
| $\beta$   | 3.2   | $Q$       | 0.001 |
| $\sigma$  | 6 dB  | $R$       | 0.01  |
| $x_0$     | 1 m   | RSS threshold (move-out) | -75 dBm |
| Velocity  | 1 m/s | RSS threshold (move-in)  | -76 dBm |
| AP coverage | 120 m | Rx sensitivity level | -90 dBm |
Foregoing experiments show that the Kalman filter [14] contributes to reducing signal fluctuations due to shadowing effects. However, RSS as a single input metric is not enough for considering vertical handoff decision. Therefore, we can still implement a fuzzy logic approach to ponder multimetric without filtering RSSs. This approach brings about fewer handoffs than the others do.

**Figure 6.** Handoff counts for different subject schemes in the move-out scenario.

4. Conclusion
This paper devised a means to fuse four types of determinants for joint decision making. We developed a Mamdani fuzzy inference system that takes into account multi-attributes of different potency to resolve a moderate decision indicative of handoff initiation. Our approach was compared quantitatively with other schemes, showing the usefulness of our development in all scenarios.

In closing, we conclude that our approach outperforms counterpart schemes in terms of reducing unnecessary handoffs effectively. Our approach enables the UE to avoid more frequent handoffs than necessary, keeping the UE from communication disruption. In another word, the UE is able to maintain seamless connection and enjoy service continuity in heterogeneous network environment.

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