Study on optimization of handoff process using fuzzy logic for mobile communication

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Abstract. This work gives a brief overview of handoff technology and how it is useful in the field of cellular communication. The work touches upon the differences and similarities between soft and hard handover. It also looks into how handoff algorithms can be optimized using fuzzy logic technology, and the various advantages of such an optimization over conventional methods of handover.

1. Introduction

The cellular concept consists of three core principles, namely – Handoff, Tessellation and Frequency Reuse. It proposes that a large coverage area is broken into smaller areas called cells that each has its own low power base station which allow for transmission of signals. These cells tesselate each other when they form small groups in order to cover a large area without any gaps or overlaps. The mobile users handoff signals when they move from one cell to another. Handoff is the process of transmitting a signal from one base station to another in order to prevent the loss of that signal. Handoff allows users to be mobile by providing the networks with continuous access to signal transmission.

Say, a user is transmitting/ receiving signals from a base station B1. Assume that the user moves from the coverage of base station B1 to another coverage area of base station B2. Base station B1 notices that the signal strength becomes weaker whereas the signal strength, from the same user, increases to B2. In turn, B1 and B2 communicate with each other in order to transfer the user’s signal from B1 to B2 ‘figure 1’. In this way, handoff is achieved.

Handoff not only requires the identification of a new base station, but also requires that new voice and control channels be allocated with regard to that new base station.

The parameters that induce the quality of communication during handoff are usually the Received Signal Strength (RSS), Signal to Noise Ratio (SNR) and Bit Error Rate (BER). Each base station constantly monitors the signal strengths of all its reverse voice channels in order to determine the user’s relative location to the base station. The base station sends this information to the mobile center which then makes a decision based off the signal strengths whether a handoff is required.

In cellular communication, a dropped call is considered a more serious event than a blocked call. Hence, a fraction of the total available channels must be reserved for the purpose of conducting
handover. The time taken for handoff allows for handover requests to be queued, which can decrease the probability of a forced termination of a call due to lack of availability of channels.

Figure 1. Handoff Point [1]

2. Handoff Prioritization
Different systems have different ways of handling handoff requests. In order to prevent an abrupt termination of a call, guard channel is one of the techniques used. In this method, a fraction of the channels is reserved for managing handoff requests. It has the disadvantage of reducing total carried traffic. Although, in dynamic allocation, it allows for better utilization of the spectrum.

Queuing of Handoff Requests is another technique used to prevent call termination. It is possible due to the slight time difference between the moment that the received signal strength drops below the handoff threshold and the moment that the call is actually terminated due to insufficient signal power. The advantage is that it minimizes the chance of forced termination due to lack of available channels. The queue size and delay time is determined by the traffic pattern.

A minimum signal strength ‘P_{min}’ is defined as the minimum usable signal for an acceptable quality of voice at the base station receiver. Then, a slightly stronger signal ‘P_{HO}’ is defined as the threshold at which handover is made.

\[ P_{HO} = P_{min} + \Delta \]

If \( \Delta \) is too small, then there would be insufficient time to complete the handoff and there would be more call losses.

If \( \Delta \) is too large, there would be multiple handoffs and it would become a burden for the main switching center.

3. Parameters used in handoff algorithms
There are different metrics used to formulate a handoff algorithm. One important metric used is Received Signal Strength (RSS). It is a measure of the power received by the antenna during transmission of a signal. RSS is measured in terms of dBm and the values can vary depending on the types of antenna, the distance and the loss caused due to obstructions or other materials in the environment. Another such metric used is the Signal to Interference Ratio (SIR). The SIR is the ratio between the average received modulated carrier power to the average modulated interference power. It
is the same as Signal to Noise Ratio (SNR) for a modulated signal before demodulation. Bit Error Rate (BER) can also be used to calculate handoff strategy. The BER gives information about how many bit errors happen during transmission per unit time. Bit errors are the bits that have been altered during transmission due to some interference, distortion or synchronization errors [2].

4. Types of handoff

4.1. Soft handoff
This type of handoff entails two connections to the cell phone from two different base stations, to ensure that no break ensues during the handoff. It works on the principle of ‘make before break’. Soft Handoff is typically used in CDMA and some TDMA systems. It also helps in preventing fading through macro diversity.

4.2. Hard handoff
This type of handoff is characterized by an actual break in the connection while switching from one base station to another. The switch happens so quick that it is hardly noticeable by the user. It is a more affordable option since only one channel is required, and is sufficient where slight delays can be accommodated during the transfer such as in Internet Broadband Connections. Since it works on the principle of ‘break before make’, it can definitely cause call dropping. Hard handoff is used mainly in FDMA and TDMA.

5. Fuzzy logic
Fuzzy logic is a form of multi-valued logic where a variable can be assigned any real value ranging from 0 to 1 (inclusive), which translates to the truth value being completely true or completely false [3]. It is employed to handle the situation of partial truth.

The Fuzzy Logic architecture contains four parts:

i. Rule Base: It contains the set of IF-THEN conditions and rules in order to govern the decision making for the tuning of fuzzy controllers.
ii. Fuzzifier: It is used to convert crisp inputs into fuzzy sets. Crisp inputs include any truth values such as temperatures, pressures etc.
iii. Inference Engine: It determines what rules are to be followed according to the input fields, and these are combined to run the control actions.
iv. Defuzzifier: It is used to convert the fuzzy output back to crisp values.

The fuzziness in the arithmetic is defined by the membership function. The membership function represents the degree of truth in the fuzzy logic. Membership functions characterize whether the elements in the fuzzy sets are discrete or continuous. They are represented by graphical forms.

Some of the advantages of using Fuzzy Logic in computing are:

i. Versatility: This type of system can work with any kind of inputs whether it may be imprecise, distorted or noisy inputs.
ii. Ease: The construction and architecture of such systems is easy to understand and build.
iii. Simplicity: The concept behind fuzzy logic is of set theories in mathematics, which is quite simple to learn.
iv. Efficiency: The solutions provided by such systems are efficient since it resembles human decision making and reasoning.
v. Memory: The algorithms behind such systems can be described with little data, hence the memory required is less.
All technology has its pros as well as cons. The disadvantages of using a technology such as Fuzzy Logic is:

i. Ambiguity: Many different ways can be used to solve a particular problem, which leads to ambiguity since there is no single systematic approach in fuzzy logic.

ii. Proof: It is difficult to prove its characteristics since most times; a mathematical description is not used for the approach.

iii. Accuracy: Most times accuracy gets compromised since fuzzy logic works with precise as well as imprecise data.

5.1 Fuzzy inference systems

Fuzzy Inference Systems (FIS) are systems that use fuzzy logic sets in order to process inputs and produce outputs based on pre-specified rules. Both the inputs as well as outputs are real valued whereas the internal processing arithmetic is based on fuzzy logic.

There are two types of FIS – namely – Mamdani System and the TSK (Takagi, Sugeno, Kang) System. For the approximation of handoff parameters on MATLAB, we will be using the Mamdani FIS that is built-in to the software as part of the Fuzzy Logic Toolbox.

On MATLAB, the membership function we will be using is the Gaussian membership function in which the parameters that define the curve are the standard deviation and the peak of the curve. The Mamdani Fuzzy Inference System allows for adding various inputs and outputs. It also allows to manage the range of values.

Each variable can be fuzzified by specifying the membership function and its range.

The Range and Display Range specify the range of values that will be displayed on the graph. The Params box specifies the width and midpoint of the gaussian curve in the gaussian membership function.

6. Generic fuzzy logic based handoff

A generic adaptive handoff algorithm proposes to combine the features of various high-performance handoff algorithms in order to increase the efficiency in a dynamic cellular environment. This model allows the systematic trade-off between different system characteristics.

It is based on fuzzy logic in order to exploit the various fuzzy logic attributes such as efficient and complete utilization of system knowledge, ability to resolve conflicting requirements, and simplicity.

The steps involved in the analysis of high-performance handoff algorithm are [4]:

i. Analysis of Handoff Related System Goals: To analyse the desirable system features of the handoff algorithm in the cellular system.

ii. Determining and Pre-processing of Handoff Criteria: The handoff criteria are based on attributes like measurement availability, system requirements and desired goals. These criteria should be pre-processed before determining the algorithm.

iii. Handoff Strategy: The parameters of handoff strategy can be adapted to the algorithm by processing the criteria. The algorithm can be developed by using a suitable simulation model.

6.1. Fuzzy logic based adaptive algorithm

Major phases involved in the design of the proposed class of algorithms are [4]:

i. Identification of desirable features and associated handoff algorithm attributes.

ii. Selection and processing of handoff criteria.

iii. Determination of the basic conventional handoff algorithm.

iv. Design of a fuzzy logic system.
The conventional handoff algorithm for generic fuzzy-logic based algorithm is given by the following flow diagram ‘figure 2’:

![Figure 2. Flow Diagram for Generic Fuzzy Logic based Algorithm [4]](image)

There are three input parameters for the fuzzy-logic based algorithm, namely – Signal Interference Ratio (SIR) ‘figure 3’, Traffic Difference (TR) ‘figure 4’ and Velocity (VEL) ‘figure 5’.

The output parameters for the fuzzy-logic based algorithm are threshold of Received Signal Strength (RSS\(_{th}\)) ‘figure 6’ and the hysterisis of Received Signal Strength (RSS\(_{hys}\)) ‘figure 7’. The two parameters take seven fuzzy variables namely ‘Lowest’, ‘Lower’, ‘Low’, ‘Normal’, ‘High’, ‘Higher’ and ‘Highest’.

![Figure 3. Plot for SIR](image)
Figure 4. Plot for TR

Figure 5. Plot for velocity

Figure 6. Plot for RSSth
The rules for the fuzzy logic are generated using simple IF-THEN statements. There are twenty-seven rule combinations that can be generated from the three inputs and two outputs. It is depicted in the following table below (table 1):

**Table 1. Fuzzy logic rules [4]**

| SIR   | TR   | Velocity | RSS$_{th}$ | RSS$_{sys}$ |
|-------|------|----------|------------|-------------|
| 1     | Low  | Low      | Low        | High        |
| 2     | Low  | Low      | Normal     | Normal      |
| 3     | Low  | Low      | High       | Low         |
| 4     | Low  | Normal   | Low        | Normal      |
| 5     | Low  | Normal   | Normal     | High        |
| 6     | Low  | Normal   | High       | Lower       |
| 7     | Low  | High     | Low        | High        |
| 8     | Low  | High     | Normal     | Lower       |
| 9     | Low  | High     | Highest    | Lowest      |
| 10    | Normal| Low      | Low        | Higher      |
| 11    | Normal| Low      | Normal     | High        |
| 12    | Normal| Low      | High       | Normal      |
| 13    | Normal| Low      | Low        | High        |
| 14    | Normal| Normal   | Normal     | Normal      |
| 15    | Normal| Normal   | High       | Low         |
| 16    | Normal| High     | Low        | Normal      |
| 17    | Normal| High     | Normal     | Low         |
| 18    | Normal| High     | High       | Lower       |
| 19    | High  | Low      | Low        | Lowest      |
| 20    | High  | Low      | Normal     | Higher      |
| 21    | High  | Low      | High       | Low         |
| 22    | High  | Low      | Lower      | Higher      |
| 23    | High  | Normal   | Low        | High        |
| 24    | High  | Normal   | High       | Normal      |
| 25    | High  | Low      | Low        | High        |
| 26    | High  | High     | Normal     | Normal      |
| 27    | High  | High     | High       | Low         |
The output values can be simulated on MATLAB by specifying the above rules in the FIS system. This can be further incorporated with a handover algorithm in order to predict the most efficient way for carrying out the handoff process ‘figure 8’.

![Figure 8. Input vs Output on FIS](image)

7. Conclusions and future scope

7.1. Conclusion
Handoff Algorithms are crucial for an effective method of communication between mobile users. The conventional handover algorithms are based off multiple parameters such as Signal to Interference Ratio, Traffic Delay and Velocity of the mobile terminal. Generic Adaptive handoff algorithms work by combining multiple conventional handoff algorithms to yield the most effective performance. One way to make this possible is by using Fuzzy Logic System to predict the nature of the handoff by using Received Signal Strength as the output parameter.

7.2. Future scope
The consumer demand for access to communication is growing rapidly, and this calls for the need to continuously improve upon the existing technologies. The handoff process is just one aspect of an overall mobility framework, to provide ubiquitous access to MSs moving in a heterogeneous wireless environment. The proposed work can be further combined with various other schemes in order to attain a better quality of service. This can be achieved by testing with real time data and propagating real wireless network conditions.
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