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Implementation of Fuzzy Logic Controller for Mobile Handoff on FPGA

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---ABSTRACT---

Present wireless communication offers flexibility and mobility across cellular system. The modern cellular systems deploy smaller cells to accommodate large number of users. Due to smaller cell size area, probability of Mobile Station (MS) crossing the cell boundary increases. Thus to provide seamless connection across the cell boundary, a process called handoff has to occur i.e. when MS moves from one Base Station (BS) to another, the ongoing calls are transferred to another BS which gives best connectivity to the MS. This paper consists of a Fuzzy logic based Handoff Decision (FHD) approach to predict the correct and efficient handoff decision, thus preventing unnecessary handoffs and therefore ensure the Quality of Service (QoS). The Matlab tool is used for designing the Fuzzy Inference System (FIS) to process the handoff decision metrics and the proposed FHD is implemented on FPGA. A hardware implementation provides faster handoffs decision making compared to a software approach. Also, FPGA implementation offers flexibility, and reduced design time, this device is chosen to implement the Fuzzy Logic Controller (FLC) for handoff decision.

KEYWORDS : *FHD, QoS, FIS, FLC, FPGA.*

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I.   INTRODUCTION

Wireless communications have emerged since from many decades. In cellular system, the MS needs to be connected to other multiple points i.e. number of Base Stations and cellular systems as MS moves from one BS to another. The process of supporting the change from one wireless point of connection to another is referred to as handover or handoff. Handoff is the mechanism by which an ongoing connection between a MS and BS within the cellular system is maintained. In today's cellular system, the cell size is reduced to accommodate large number of users. Due to small cell size, the probability of MS crossing a cell boundary increases and thus handoff occurs frequently [1].

Also signal level degrades due to frequent handoffs, affecting the QoS provided to the users. Thus it is necessary to develop efficient handoff decision algorithms to predict the right handoff. Since traditional predictions method of handoff decisions based on only signal strength do not perform well as they cause large number of unnecessary handoff, it is essential to develop an intelligent approach to facilitate the handoff prediction process based on multiple criteria of dynamic cellular environment [2]. A number of algorithms are being investigated, that employs comparisons of various parameters like Received Signal Strength (RSS), speed of mobile user, bandwidth etc. from neighboring BSs with the current serving BS and based on this, decision is made whether to make handoff or no. The main aim of this paper is to propose the FHD algorithm to predict the efficient handoff decision and implement the FLC for handoff control on FPGA. FLC is control algorithm based on a linguistic control strategy, which is derived from human expert knowledge. FLC doesn't need any difficult mathematical calculation like other control system and offers better performance in a control system [3]. In this paper, an FPGA implementation of the FHD has been implemented. In section2, we have discussed about FLC, two different methods of FLC, FLC components and design of FLC for handoff decision. In Section 3, implementation of proposed fuzzy logic handoff controller on FPGA is shown. Results, simulations and utilization summary are included in sections 4, 5 and 6. Section 7 gives the conclusion.

II.   FLC FOR HANDOFF DECISION

2.1 Introduction to FLC

The FLC deals with the uncertainty and imprecise data. Fuzzy system are gaining widespread acceptance in a large variety of fields. Fuzzy logic can control nonlinear systems that would be difficult or impossible to model mathematically. Thus this can be applied for control systems that would be unfeasible for automation. There are two methods used in Fuzzy Logic Controller [4]. Mamdani type Fuzzy Inference method and Sugeno type Fuzzy Inference method are discussed in this paper.

a) Mamdani type Fuzzy Inference method

Mamdani method was the first efficient FLC designed for complex systems. Mamdani type inference expects the output membership function to be fuzzy sets. After the aggregation process, there is a fuzzy set for each output variable that needs defuzzification. The main limitation is that defuzzification process requires more computation time.

b) Sugeno type Fuzzy Inference method

This method is similar to Mamdani method except that the output membership functions are single spikes, also known as singleton. The output membership functions are either linear or constant. This method enhances the efficiency of defuzzification process as it simplifies the computation time.

In our work we use Sugeno method, because it is computationally efficient than Mamdani method.

2.2 Block Diagram of FLC

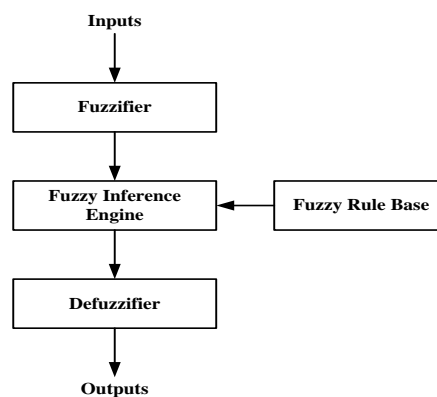The block diagram of FLC is shown in Fig 1.

Figure 1: Block diagram of FLC

There are three components of a FLC:

a) Fuzzification module (Fuzzifier)
b) Rule base and Inference engine
c) Defuzzification module (Defuzzifier)

a) Fuzzification module

Fuzzification module converts the crisp value (from real world) into a linguistic variable (fuzzy set). Membership functions, a graphical representation are defined for each fuzzy set. There are different types of membership functions. Trapezoidal and triangular are widely used because of its computational efficiency.

b) Rule base and Inference engine

A set of rules specifying combination of input membership are stored. The fuzzified variables are passed to the inference engine and utilizing if-then rules the variables are compared to produce the output fuzzy sets.

c) Defuzzification module

This module converts the output fuzzy set generated by each rule into a single crisp value. There are many defuzzification methods. The two most common defuzzification methods are:

i) Maximum Value Method

The maximum value method bases the final output value on the rule output with the highest membership function grade. This method is mainly used with discrete output membership functions.

ii) Center of Gravity Method or Centriod method

The center of gravity method, also referred to as "calculating the centroid," mathematically obtains the center of mass of the triggered output membership functions. The center of gravity method is the most commonly used defuzzification method because it provides an accurate result based on the weighted values of several output membership functions. Thus the final crisp output is given by

$$crisp\ output = \frac{\sum_i^n (fuzzy\ output) * (singleton\ positions\ on\ x\ axis)}{\sum_i^n (fuzzy\ output)} \qquad (1)$$

2.3 Design of FLC for Handoff Decision

The following section describes the development of FLC for handoff decision. For our proposed FLC model, two input parameters: Distance between MS and BS and Received Signal Strength (RSS) are considered and one output variable handoff decision is defined. Trapezoidal membership functions are defined for each of these inputs whose degree of membership varies from 0 to 1.

The Matlab Tool is used to generate the FIS for proposed handoff decision. The graphical representation of input variable is shown in Fig 2 and Fig 3. As shown in the following figures,

a) First input, Distance between MS and BS has three fuzzy sets: Near, Medium and Far.

b) Second input, RSS has three fuzzy sets: Weak, Medium and Strong.

c) Output, Handoff decision has three fuzzy sets: Handoff (H), Be-careful (B) and No Handoff (N).

In our proposed paper Sugeno method is used, so output variables are represented as singletons. Center of gravity method is used for defuzzification process.
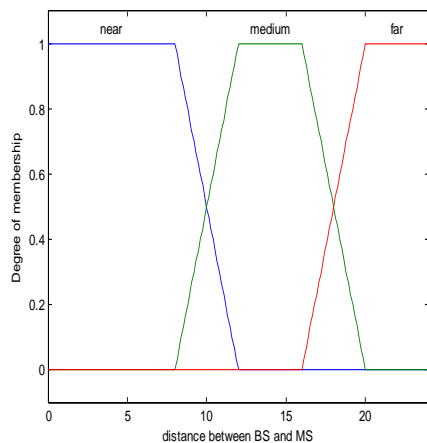
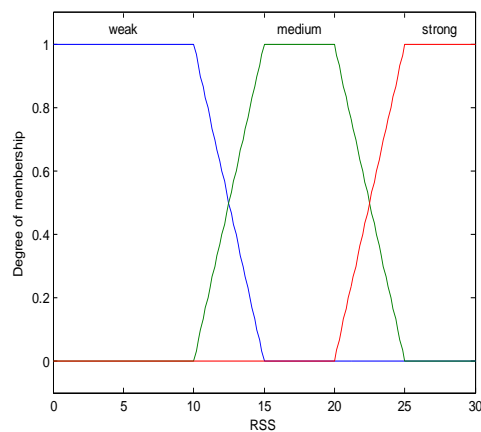Figure 2: Membership functions for distance Between MS and BS
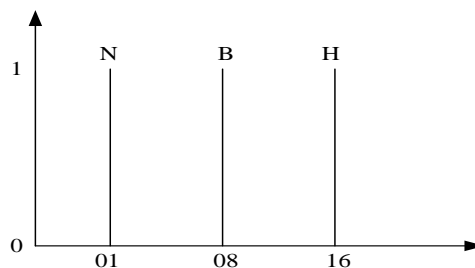
Figure 3: Membership function for RSS

Figure 4: Membership functions for output decisions

Since there are two fuzzy input variables each with three fuzzy sets, possible number of rules are 3 *3=9. The fuzzy rule base table is generated as shown in Table 1 [1].

Table 1: Fuzzy Rule Base for Proposed Handoff Controller

Roll No	Distance	RSS	Handoff Decision
1	Near	Weak	Handoff
2	Near	Medium	No handoff
3	Near	Strong	No handoff
4	Medium	Weak	Handoff
5	Medium	Medium	Be -careful
6	Medium	Strong	Be-careful
7	Far	Weak	Handoff
8	Far	Medium	Be-careful
9	Far	Strong	No handoff

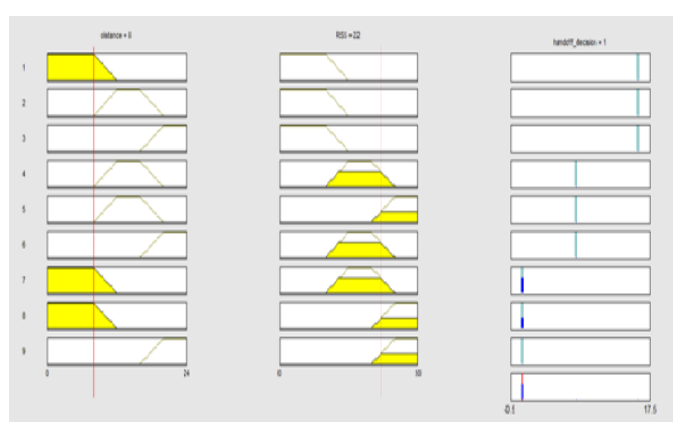2.3.1 The Matlab rule viewer display of above combined if-then rules is shown in Fig 5.

Figure 5: Rule view display of combined if-then rules

From above Fig 5, it can be shown that, when distance is 8m and RSS is 22mW then output decision is no handoff.

2.3.2 The surface view for the system, showing the dependency of output on the input values is shown in the Fig 6.
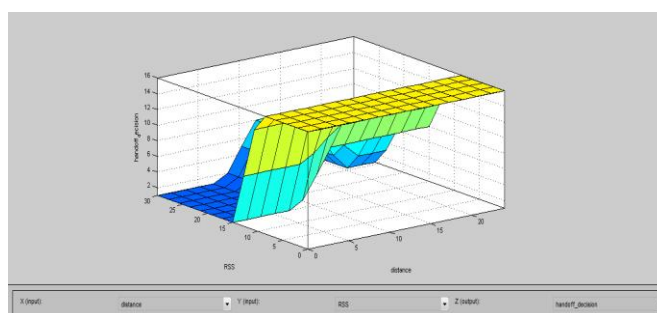

Figure 6: Surface view display

III. IMPLEMENTATION OF FUZZY LOGIC HANDOFF CONTROLLER ON FPGA

FPGA technology allows the designer to develop specific hardware architecture offering the flexibility of reprogrammable. This feature of FPGA, gives the designer a degree of freedom comparing to microprocessor and microcontroller. FPGA constitutes an appropriate target for the implementation of FLC, due to its rapid prototyping and reduced design time. To design the FLC on FPGA, each component of FLC is

designed using VHDL using 8 bit resolution computation to define wide range of input and output variables. The Fig 7 shows the block diagram of proposed fuzzy handoff controller on FPGA [1].
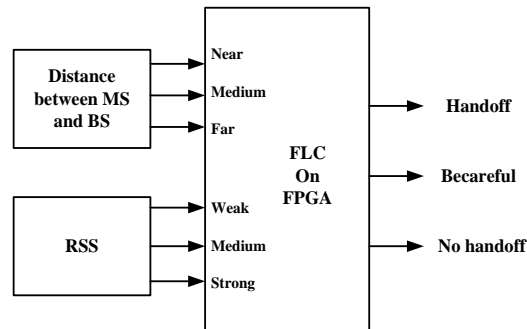

Figure 7: Block diagram of fuzzy handoff controller on FPGA

IV.   RESULTS AND SIMULATIONS

The functionality of the proposed controller is verified by simulated waveform shown in Fig 9. The Fig 8 shows the RTL schematic view.
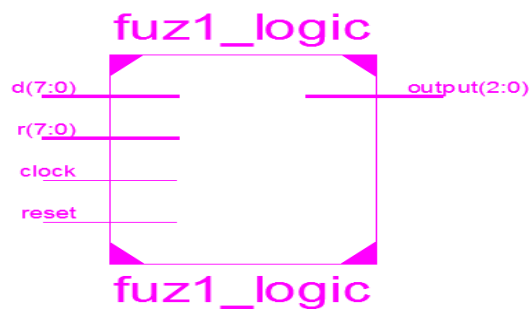

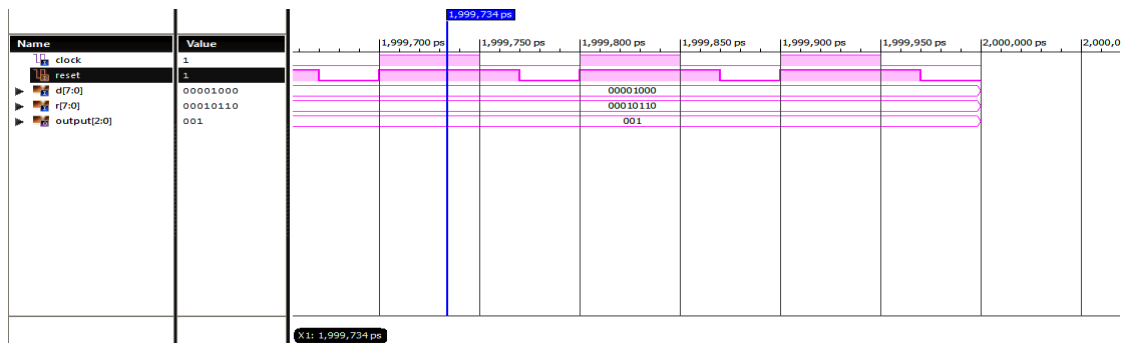Figure 8: RTL schematic of proposed fuzzy logic handoff controller

Figure 9: Simulation waveform of proposed fuzzy logic handoff controller

V. DEVICE UTILIZATION SUMMARY

Selected device – Spartan 3- XC3S200-5FT256

Number of Slices:	588	out of	1920	30%
Number of Slice Flip Flops:	165	out of	3840	4%
Number of 4 input LUTs:	1101	out of	3840	28%
Number of IOs:	21			
Number of bonded IOBs:	21	out of	173	12%
IOB Flip Flops:	3			
Number of MULT18X18s:	4	out of	12	33%
Number of GCLKs:	1	out of	8	12%

VI.   TIMING SUMMARY

Speed Grade: -5
Minimum period: 14.294ns (Maximum Frequency: 69.960MHz)
Minimum input arrival time before clock: 11.361ns
Maximum output required time after clock: 6.141ns
Maximum combinational path delay: No path found

VII.   CONCLUSION

In this paper we have implemented, FHD approach for predicting the handoff in cellular system. For designing the FLC, a high- level modeling approach in VHDL has been used. The advantage is reducing the design time and realizing the design functionality in a short time. The results show that the fuzzy logic based handoff decision algorithm is an efficient algorithm as it processes the imprecise data and its hardware implementation is capable of responding to the fast changes that occurs in cellular environment.

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BIOGRAPHIES

Krupa R. Rasane has completed her M-Tech in Electronic Design and Technology from C.E.D.T.I, Aurangabad. She has submitted her PhD thesis in the area of Image Compression using VLSI at Visvesvaraya Technolgical University, Belgaum. She is at present the Associate Professor and Head of the Department in the E&C Department at KLE DR. MSSCET Belgaum.

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