Optimal Access Guarantee in Hybrid Access Femtocells Using Fuzzy Logic System

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Optimal Access Guarantee in Hybrid Access Femtocells Using Fuzzy Logic System

Waheed Moses Audu, E. N. Onwuka, O. Ugweje and M. A. Aibinu

Abstract—Determining the optimal access guarantee level for hybrid access Femto cells remains an unsolved component of Femto cell development. In this paper, we present a hybrid access scheme that uses Signal-to-interference plus noise ratio (SINR) and channel (time) availability for determining the appropriate access guarantee level. These parameters can be easily obtained by the Femto device's self-configuration and initialization capability. Fuzzy logic scheme employing the Mamdani system was used for processing due to its simplicity and manageable trade off in accuracy. A Sugeno system was then included in the two stage Fuzzy Inference System to achieve the desired result. In our results, we present an Access Guarantee metric that was used to determine the optimal access region. An Access Guarantee value of about 45.6% was obtained in our simulation specific environment.

Index Terms—Channel, Femtocell, Fuzzy logic systems, Hybrid Access, SINR.

1 INTRODUCTION

An investigation into wireless network user activity shows that, more than half the increasing population are serviced data and voice calls to indoor locations [1]. These include private and public premises. With the advent of smart phones, migration from voice to data centred applications has driven the need for larger bandwidth networks [2]. Furthermore existing macrocells have evolved from 2G to 3G and 4G standards to satisfy these demands while ensuring high user Quality of Service (QoS). However, certain considerations need to be addressed regarding this drift. For example, higher frequencies of newer generation systems in indoor scenarios are attenuated greatly with increase in distance. It therefore makes broadband connection difficult to attain. This can be inferred from (1):

$$P_r = P_t\left(\frac{\lambda}{4\pi d}\right)^2 G_b G_m \qquad (1)$$

P_r and P_t represents the received and transmit power respectively. The wavelength of the signal is denoted by λ while G_b and G_m stand for the gain of transmitting (base station) and receiving (mobile) antenna. From (1), the lesser the cell size the greater the signal reception. Variation in cell size is shown in Table 1 [3]. Femtocell technology avails among others as a solution to the indoor coverage and capacity problem [4].

Table 1: Cell variations in Telecommunications

Cell type	Coverage area	Application
Macrocell	3-35Km	rural
Microcell	100m – 1Km	urban
Picocell	10m- 1Km	rooftops
Nanocell	1 – 10m	below rooftops
Selective , Sectorized or tiered cells	Less than 360°	tunnels – 120°
Umbrella cells	Overlays several small cells	reduce frequent handoffs
Femtocells	20 -30m	indoor

A Femtocell is an indoor base station (BS) operating, at low power, licensed spectrum with small coverage area of 20-30m radius [5]. A major component of the Femtocell technology is the Femto Access Point (FAP). FAP draws similarity to a WiFi access point (AP). FAPs operate either an open or closed access scheme. Recent trends have resulted in a hybrid scheme of both open and closed operation. However, a major concern lies in determining the access guarantee level for the hybrid operation. In this paper, we address this issue by developing an approach to determining the optimum access guarantee level using fuzzy logic.

We present the rest of the paper as follows: Part 2 presents a review of related works. Part 3 shows a proposed methodology. Part 4 provides the results and discussion of the results obtained. Part 5 presents the conclusion and future works.

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2 THE CONCEPT OF FAP

A FAP connects to the operator network over a broadband internet protocol (IP) network using Digital Subscriber Line (DSL), cable modem or a separate RF. Figure 2(a) gives a pictorial view of the setup. It can be observed from figure 1 that 2G, 3G and 4G Femtocells can exist in the same domain. This implies that mobile users connect to the FAP wirelessly at radio frequencies (RFs) within an overlay macro cell. FAPs are user deployed thereby saving service providers the cost (energy, site lease, equipment purchase and upgrade) incurred in network expansion options [4].

However, user deployed nature of Femtocells introduces the challenge of network planning. A decentralised planning is used by introducing a Femto management system (FMS) for FAP self-initialization and optimization [8]. Figure 2(b) shows how the device provides network convergence with wireless local area network (WLAN). This is necessary to meet the emerging trend of an all IP network.

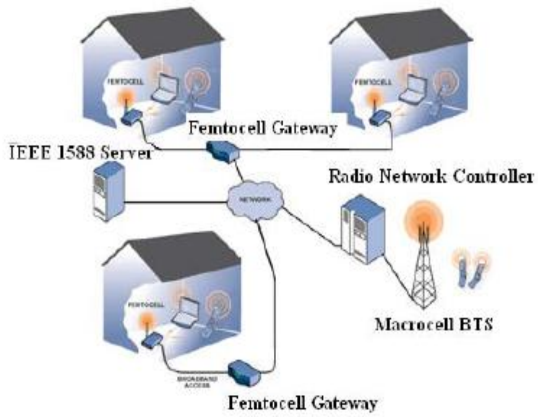

Fig. 2(a): Femtocell network's fundamental entities [6].

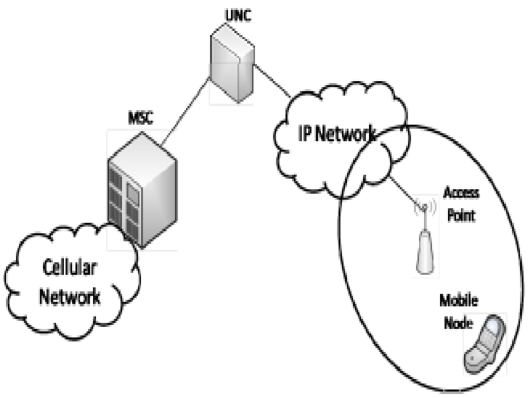

Fig.2 (b): Cellular/WLAN convergence architecture[7].

Accurate timing and synchronization of FAPs is needed to avoid packet delays and/or losses for effective hand off and location management [2], [5]. Furthermore, access control is needed for owner's privacy and in case of emergency calls. In this respect, a FAP operates a closed access (CA) when only home subscribers can use the device. It results in harmful interferences on Femto devices from nearby macro cell mobile station (MS) in the uplink. In the downlink Femto devices interfere with signal received by macro cell MS from its serving BS. In open access (OA) there are no restrictions to the FAP. This raises the issue of multiple hand-off from Macro to Femto and Femto to Macro by Macrocell MS. Open access has been found to perform better in terms of throughput rate and reduced interference [11], [13]. It was observed that most FAP owners prefer CA to OA [10], [11]. This enables maximized usage of its resources. The resources in terms of IP connection and the device itself are paid for by interested home owners. Addressing the dichotomy between the desire for OA and CA has accelerated the concept hybrid access [10].

3 INTRODUCING HYBRID SCHEMES AND FUZZY LOGIC

There are different possible solutions to the hybrid models depending on frequency/time sharing with respect to nonsubscribers [12]. This is needed for the common interest of paying home owners, passing macro BS users and achieving operator's network capacity expansion goal. Therefore all hybrid models are expected to give control of the FAP to the paying subscriber at the same time share its resources with roaming mobile terminals. Most issues highlighted can be managed by the hybrid access control. A fuzzy logic approach is considered here as a possible solution.

In fuzzy logic, imprecise data are taken as input variable(s) which are combined by a set of vague statements to give a decisive output [14]. The combination is done in the fuzzy inference system (FIS) engine. The common FIS comprise basically of the Mamdani and Takagi-Sugeno systems. The Mamdani's method is more intuitive, has wide spread acceptance and better suited to human input [14]. Sugeno's method is computationally efficient, works well with linear techniques, has guaranteed continuity of the output surface, better suited to mathematical analysis, works well with optimization and adaptive techniques [14]. Motivated by this idea, we present a simulation framework using Fuzzy Inference System (FIS) to decide when MUs gain access to a Femtocell. The developed system ensured that acceptable throughput rate is maintained for both MUs and FUs at all times.

4 SYSTEM DESIGN, SIMULATION AND RESULT INTERPRETATION

In our design, we retain the assumption that preferences are given to FU in any channel. However, our decision framework aims to maintain optimal performance at most or all of the time. The flowchart algorithm and block diagram is as shown in Figure 3 and 4.

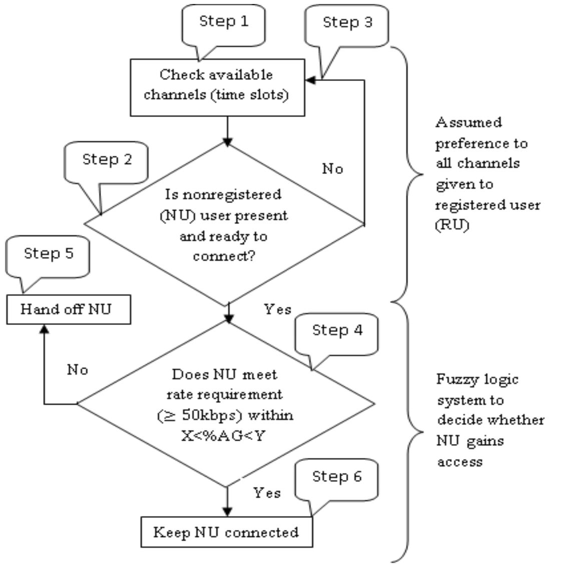

Fig. 3: Flowchart Algorithm of Developed Hybrid Access Scheme

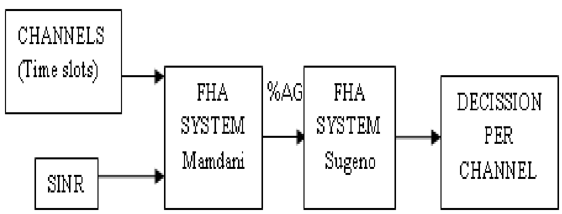

Fig. 4: Block Diagram Showing a Proposed Hybrid Access Mechanism Using FIS

For a 5 MHz signal bandwidth with an expected 500kbps and 50kbps throughput for FU (registered users (RU)) and MU (nonregistered user (NU)) respectively, signal-to-interference plus noise ratio (SINR) can be obtained from Shannon Hartley theorem:

$$C = B\log_2(1 + \frac{S}{N}) \quad (2)$$

$(S|N)$ In decibels is:

$$(S|N)dB = 10\log_{10}[(\sqrt[B]{2})^C - 1] \quad (3)$$

When B = 5 MHz and C=500kbps

$$(S|N)dB = -11.549$$

When B = 5 MHz and C=50kbps

$$(S|N)dB = -21.549$$

Furthermore, we assumed that an eight (8) channel (time slots) was available for both users. However, preference was given to RU operating in a system of 8 active simultaneous users. The FIS engine takes in as input the value of both available numbers of channels for usage by FU/RU and their SINR. We modelled the behaviour of the input variables (available channel and SINR) using MFs. The output of the first stage of the block gives access guarantee level in percentages. Figure 3(a) shows a schematic FIS editor. The Implication, aggregation and defuzzification methods are unchanged.

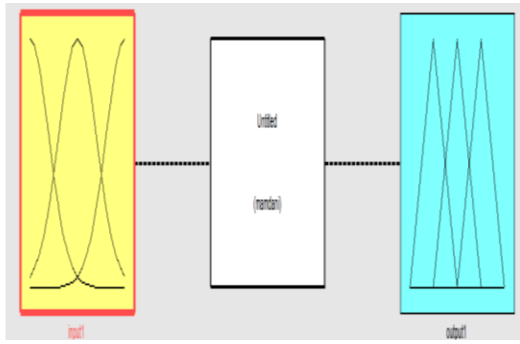

Fig. 3a: An untitled FIS editor

The input name is changed to 'available channels (time-slots)' and the MF is edited appropriately. The rules were edited as shown in Figure 3(b):

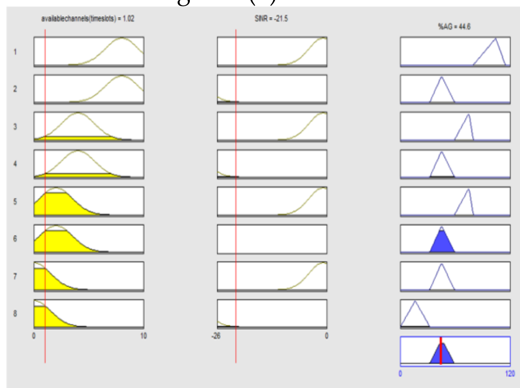

Fig. 3(b): Rule viewer for edited FHAm

The fuzzy sets of rules are as follows:

1. IF available channel is 5-8 AND SINR is ≥ -11.549 THEN %AG is Unlimited (U)
2. IF available channel is 5-8 AND SINR is< -21.549 THEN %AG is Poor (P)
3. IF available channel is 3 / 4 AND SINR is≥ -11.549 THEN %AG is Average (A)
4. IF available channel is 3 / 4 AND SINR is< -21.549 THEN %AG is Poor (P)
5. IF available channel is 2 AND SINR is ≥ -11.549 THEN %AG is Average (A)
6. IF available channel is 2 AND SINR is< - 21.549 THEN %AG is Poor (P)
7. IF available channel is 1 AND SINR is ≥ -11.549 THEN %AG is Poor (P)
8. IF available channel is 1 AND SINR is < -21.549 THEN %AG is Very poor (VP)

The resulting rule and surface view are shown in Figure 3(c) and 3(d). From the rule viewer the worst case scenario is envisioned by a channel availability of 1 and SINR remained at its threshold value for optimal performance.

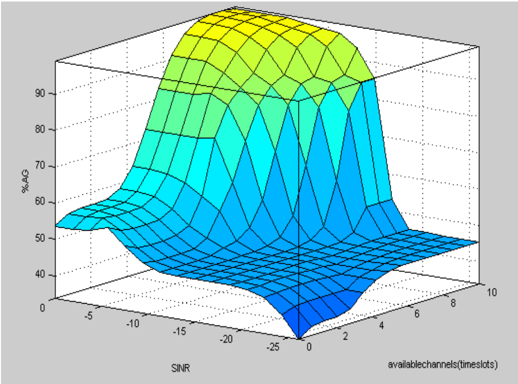

Fig. 3(c): Surface viewer for edited FHAm

The consequence is a %AG of 44.6. This result is acceptable coupled with the smooth transition of the respective surface view of Figure 7. The best case for NU would be to find the %AG that result in an availability of eight (8) channels. The result obtained from the rule viewer of Figure 8 shows a value of 45.6 corresponding to %AG.

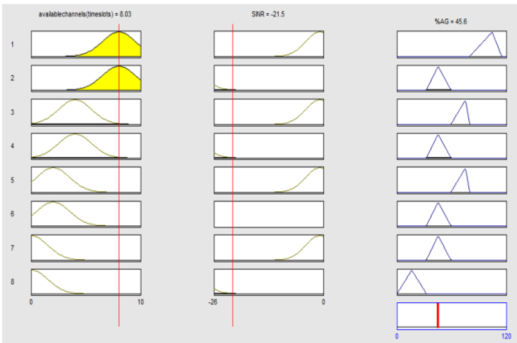

Fig. 3(d): Rule viewer 2 for edited FHAm

From these results, the following deductions were made:

1. IF %AG $<$ 44.6 THEN Handoff any NU
2. IF %AG $>$ 45.6 THEN Presence of RU
3. IF 44.6 $\leq$ %AG $\leq$ 45.6 THEN permit NU

These can be implemented in the second stage of the FIS in the block diagram of Figure 4. In this case, a Sugeno model is chosen due to its constant type MF. The surface viewer and three distinct case of rule viewer are shown in Fig. 3(e)-3(h).

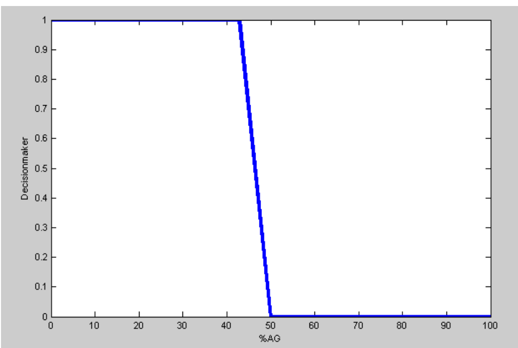

Fig. 3(e): Surface viewer for FHAs

Processing the output rules deduced from figure 8 resulted in an optimum value for the Access Guarantee (AG) variable. Figure 9 shows the transition of the decision maker against the AG level. From 0 to 44.6 % AG value, the decision maker outputs a value of 1. This informs the system that only the RU should be given occupancy rights. The steep slope between AG values of 44.6 to 45.6% indicates a region of decision making. Afterwards, AG values above 45.6% present a region where MU can have access rights along with the RU. This hybrid scheme successfully develops a unique method using the AG variable to determine the optimum regions for RU and MU co- existence. Furthermore, below the 44.6% AG value, the system preserves the Quality of Service of the RU user as required.

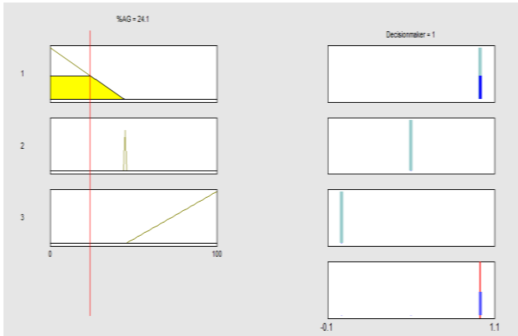

Fig. 3(f): Rule viewer 1 for FHAs

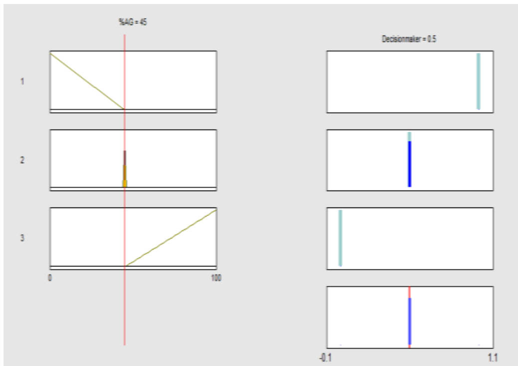

Fig. 3(g): Rule viewer 2 for FHAs

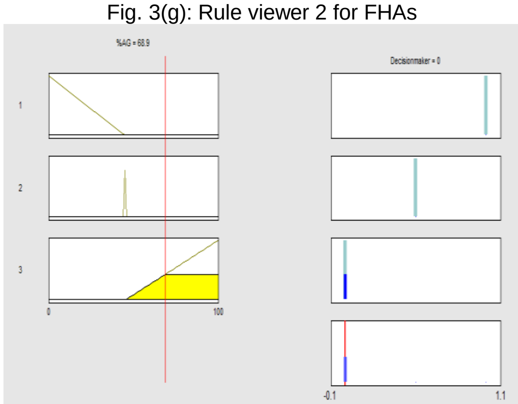

Fig. 3(h): Rule viewer 3 for FHAs

6 Conclusion

In this paper, a hybrid access scheme that determines the optimal access guarantee (AG) level using fuzzy inference system was developed. This scheme employs a low complexity algorithm for determining optimal regions for mutual co-existence between registered users RU and Mobile Users MU. It ensures that the Quality of Service experienced by the RU was maintained while ensuring possibility of MU access at defined AG values. This Fuzzy system adaptively combined the Mamdani and Sugeno systems to achieve optimality. For specific simulations, an optimal AG value of 45.6% was achieved for hybrid co-existence of RU and MU users. Implications of this result were presented in the result discussion section. For future works, this algorithm can be further enhanced to incorporate a billing system that charges NUs depending on the QoS demand.

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