On Achieving Self-Organization in Mobile WiMAX Network

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***Abstract*—Mobile communication systems are moving towards the use of small cell technology to support low latency and high bandwidth applications. This trend is leading to higher operational costs as the number of base stations (BSs) to be managed will increase in proportion to the number of cells. The concept of a Self-Organizing Network (SON) has been proposed as a solution to reduce operational costs and quickly respond to customer needs. In this paper, we propose a SON solution that uses fuzzy logic to support self-configuration and self-optimization mechanisms. We define three fuzzy logic input metrics, four membership functions, and twenty-seven fuzzy rules to implement fuzzy logic controller of the solution. The solution is then validated in a mobile WiMAX simulation environment. Three different scenarios are simulated and the results are evaluated using different metrics. The results show that the proposed solution is efficient and improves the overall performance of a SON-based mobile WiMAX network.**

***Index Terms*—Self-Organizing Network, Mobile WiMAX, Network Management, Fuzzy Logic**

I. Introduction

LTE-Advanced [1] and IEEE 802.16m [2] are potential candidate technologies for IMT-Advanced [3], which is a next-generation mobile communication standard. Both technologies are evolving towards supporting low latency and high bandwidth for users, while improving the system capacity and coverage for service providers. We have to increase the number of base stations (BSs) and reduce the coverage area of each BS to achieve these goals, because radio resources are limited. Increasing the number of BSs needed to cover the same area, however, leads to higher interference and higher operational costs. Therefore, reducing operational costs is very important and it is one of the biggest challenges for service providers.

Configuring and optimizing cellular networks are very complex tasks, because we have to consider many related parameters including traffic distribution, topography, morphology, and existing infrastructure. If we consider the various system constraints including frequency range, system capacity, quality of service (QoS), and interference, these tasks become even more complicated. Current cellular network management systems rely heavily on human experience and intuition in conjunction with network planning tools, so it is very hard to respond rapidly to changing customer needs. Therefore, future network management techniques should be able to minimize human intervention, set their own parameters, optimize these parameters, and heal problems by themselves when they occur.

The *Self-Organizing Network* (SON) concept was proposed by 3GPP LTE-Advanced [1] and IEEE 802.16m [2] to reduce operational costs for service providers and to respond quickly to customer needs. SON is defined as a process that monitors the status of a network and automatically configures, optimizes, and heals itself when the network status changes. SON is expected to play a key-role in next-generation mobile communication networks, so related research and standardization is being carried out at a fast pace. However, the research and standardization are still at an early stage. For example, [4] just derives the requirements of SON, and [5] only suggests use cases. Therefore, we need to do more realistic and specific research regarding SON.

In this paper, we propose a novel method that monitors the network status, and autonomously changes the transmission power level without intervention to maximize area coverage and traffic coverage while minimizing interference and power consumption. The proposed method uses *fuzzy logic* to represent ambiguous constraints, for example, "*the traffic load is high*", and changes the transmission power level based on fuzzy rules. The proposed scheme was validated via three different scenarios in a mobile WiMAX [6] simulation environment.

This paper is organized as follows. Section 2 summarizes the related work on SON including the basic concepts, auto-

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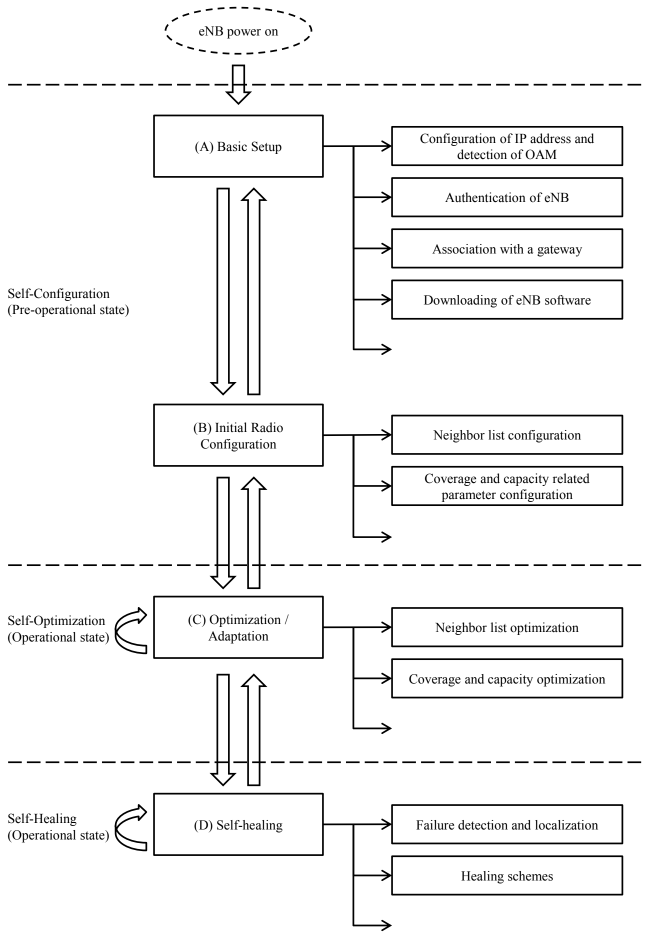

Fig. 1. SON functionality of 3GPP LTE-Advanced.

matic cell planning, and optimization. Section 3 presents the proposed method. Section 4 describes our simulation environment and Section 5 shows the simulation results. Concluding remarks and possible future work are given in Section 6.

II. Related Work

A standardization framework for SON is under development in 3GPP LTE-Advanced [1] and IEEE 802.16m [2]. Use cases related to Self-establishment, Physical cell ID, Automatic neighbor relation, and Inter-cell interference coordination were proposed in 3GPP LTE-Advanced Release 8, which was announced in March, 2009. SON is divided into three parts; *Self-configuration*, *Self-optimization*, and *Self-healing* as illustrated in Fig. 1 [7].

The *Self-configuration* is a process where parameters are automatically configured including the IP address and physical cell ID of newly deployed BSs. The *Self-configuration* process works in the pre-operational state, and it consists of two parts; the *basic setup* and the *initial radio configuration*. Sample use cases of each stage are described in the boxes on the right hand side in Fig. 1: 1) Configuration of IP address and detection of Operations, Administration, and Maintenance (OAM) server, 2) Authentication of enhanced Node-B (eNB), 3) Association with a gateway, and 4) Downloading of eNB software for *basic setup* stage along with 1) Neighbor list configuration and 2) Coverage and capacity related parameter configuration for *initial radio configuration* stage.

The *Self-optimization* is a process that continuously monitors an environment and automatically optimizes various parameters when the environment changes. This process works in the operational state. Example use cases are 1) Neighbor list optimization and 2) Coverage and capacity optimization.

The *Self-healing* process automatically detects failures, localizes them and fixes the problems by itself. This process also works in the operational state in the same way that the *self-optimization* process works. The *self-optimization* and the *self-healing* form a control loop which means these processes are executed periodically, while *self-configuration* is done once only at the time when the newly deployed BSs is turned on or reset. The use cases of the *self-configuration*, *self-optimization*, and *self-healing* can be extended. The basic concepts of SON in IEEE 802.16m are similar to 3GPP LTE-Advanced SON.

There are several ongoing projects addressing SON issues. The goal of the Gandalf project [8] is to develop large-scale network monitoring, Advanced Radio Resource Management (ARRM), parameter optimization, and configuration management techniques to achieve the automation of network management tasks in a multi-system environment. An important part of this project is developing techniques to collect and process data on a large scale network in order to produce key performance indicators to identify malfunctions and to perform healing actions dynamically.

The SOCRATES project [9] aims to develop self-organization methods to enhance the operation of wireless access networks, by integrating network planning, configuration, and optimization into a single, mostly automated process requiring minimal manual intervention. From the technical point of view, SOCRATES primarily focuses on wireless access networks. The bottleneck in end-to-end communications generally occurs in the wireless segment, so managing wireless access networks is important both in terms of operational complexity and network costs.

Vendors are also active in the field of SON. Recently Motorola has announced an advanced SON solution which is a part of its LTE offering. Other vendors such as NSN, Ericsson, Samsung, and Huawei are also working intensively on their SON solutions.

Previous work on optimizing cellular networks focused on automatic cell planning. Huang and *et al*. [10] used fuzzy logic for automatic cell planning. The authors considered traffic load and interference for fuzzy logic inputs, and changed the transmission power as a result of fuzzy inference. They validated their solution in a GSM network simulation environment that followed a simple Unit Disk Graph Model [11]. They used fuzzy logic to optimize the cell parameters, but they did not consider the dynamic change of the cell environment. For example, the number of cells can change based on the requirements of users. Operators are able to add a new BS

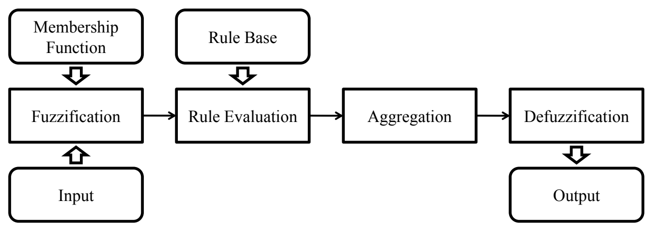

Fig. 2. Mamdani fuzzy inference system.

for the better performance of adjacent cells or areas. Liao and *et al*. [12] also proposed a self-organization scheme for cell configuration. They used reinforcement-learning technique to dynamically adjust pilot frequency and data frequency allocation ratio. In contrast to [10], our work focuses not only on the cell planning stage, but also on the servicing stage, which means BSs optimize autonomically or automatically related parameters by themselves even when they are in the operational state, whereas [10] only focused on the cell planning stage. Moreover, the proposed solution in this article also considers the coverage area, in addition to traffic load and interference. We also validated our work in a mobile WiMAX [13] simulation environment and considered more realistic parameters.

III. Self-Organizing Network Using Fuzzy Logic

Fuzzy logic is a methodology to represent vague language, such as big or small, and it allows flexible engineering design but is simple to implement. Due to these benefits, fuzzy logic is widely used for various applications including air conditioning, digital image processing, elevator control, and pattern recognition. The parameters that are used in our proposed SON are ambiguous in many cases, for example, the constraints "*traffic load is high*" does not specify a concrete traffic load level. We can represent these ambiguous parameters easily, and make a decision based on fuzzy rules by using fuzzy logic. In this section, we briefly describe the Mamdani Fuzzy Inference System (FIS) [14] and define input metrics, membership functions, and fuzzy rules.

A. Mamdani Fuzzy Inference System

There are several types of FIS including Mamdani FIS [14] and Sugeno FIS [15]. We used Mamdani FIS in our proposed method, because it has a greater expressive power and interpretability than Sugeno FIS [16]. Mamdani FIS has four steps; *Fuzzification*, *Rule evaluation*, *Aggregation*, and *Defuzzification* as illustrated in Fig. 2.

In the *Fuzzification* step, FIS gets real values as inputs from outside of the process, and then evaluates these values using membership functions. We defined three input metrics and four membership functions in Section III.B and III.C, respectively. The membership function represents the degree to which a variable could be contained in a fuzzy set. The degree is a value between 0 and 1; the closer the degree is to 1, the more likely it is that the variable is contained in a fuzzy set. For instance, if a man's height, which is 170 cm, is entered as an input, then the membership function can evaluate whether this man is tall or short. The evaluated results are passed to the *Rule evaluation* step.

In the *Rule evaluation* step, membership values that were passed from the *Fuzzification step* are evaluated using fuzzy rules which are stored in the *Rule base*. For example, let's assume that we have a rule as follows:

"IF father IS short AND mother IS short,
THEN child IS short."

FIS takes the father and mother's height measurement, translates these values into fuzzy sets using the membership functions in the *Fuzzification* step, and then decides the child's height based on the rules in the *Rule evaluation* step.

Every result that was evaluated by fuzzy rules in the *Rule evaluation* step is aggregated into one fuzzy set for each output variable in the *Aggregation* step. The output fuzzy sets are converted into crisp output values in the *Defuzzification* step. Finally, the crisp output values are used by the system which is outside of the FIS. In our scheme, we used the FIS output value to dynamically change the transmission power.

We defined three input metrics and three input membership functions for the *Fuzzification* step, and defined twenty-seven fuzzy rules for the *Rule evaluation* step. We also defined one output membership function for the transmission power change. From the various available *Defuzzification* methods, we used the *Center of Gravity* (CoG) method, which finds the point where a vertical line would slice the aggregate set into two equal sections.

B. Input Metrics

Enormous amounts of parameters including interference, number of users, traffic load, coverage area, and terrain should be considered for SON. However, it is impossible to consider all of the parameters. In this article, we define the three essential input metrics and use them as inputs to the FIS as follows:

1) Area Coverage Radius (r_{BSi}): We assumed that the coverage area of a cell has a circular shape and this metric (r_{BSi}) is the radius of the circle area that is covered by BS i. The *Area Coverage Radius* changes depending on the transmission power. We used the Free Space Path Loss (FSPL) Model [17] to obtain r_{BSi} from the transmission power.

2) Traffic Load (T_{BSi}): We assumed that the service area is given and the entire area consists of $n \times m$ pixels. The *Traffic Load* is a metric that represents the entire traffic load in the area covered by BS i. That is:

$$T_{BSi} = \sum_{x=1}^{n} \sum_{y=1}^{m} \delta(x,y) \cdot p_{BSi}(x,y), \tag{1}$$

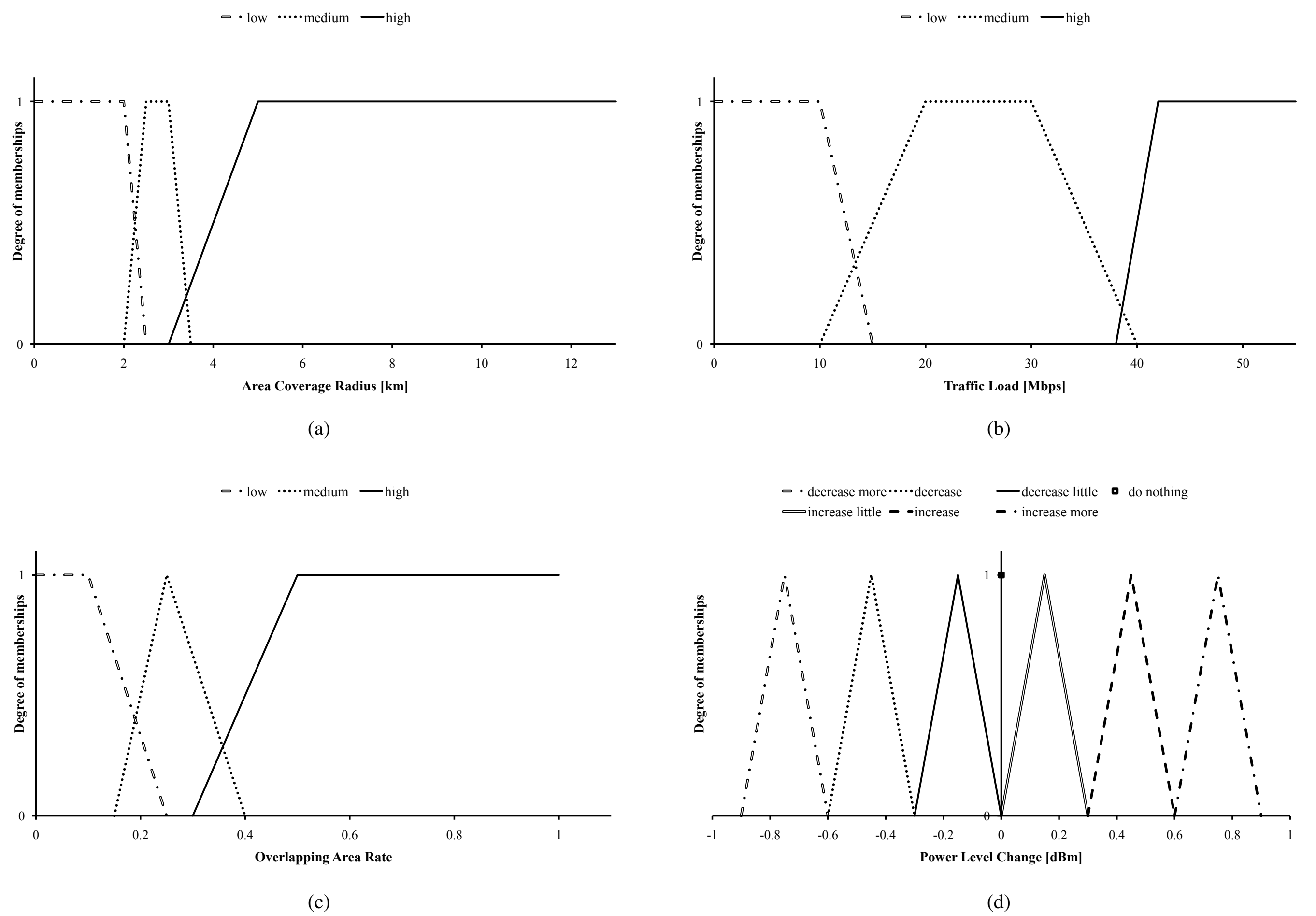

Fig. 3. Membership Functions: (a) Coverage Radius following FSPL Model, (b) Entire Traffic Load of a BS, (c) Overlapping Area Rate between a BS and other BSs, and (d) Power Level Change resulted from fuzzy inference.

where $\delta(x, y)$ is the traffic load at pixel (x, y) and $p_{BSi}(x, y)$ is a function that indicates whether pixel (x, y) is covered or not by BS i, i.e., 0 if it is not covered and 1 if it is covered.

3) Overlapping Area Rate (O_{BSi}): This metric represents the rate of the overlapping area between BS i and neighbor BSs. That is:

$$O_{BSi} = \frac{\sum_{x \neq i} \varphi(BS_i, BS_x)}{\pi r_{BSi}^2}, \tag{2}$$

where $\varphi(BS_i, BS_x)$ is the overlapping area between BS i and BS x. Inter-cell interference is directly influenced by the *Overlapping Area Rate*, i.e., a large O_{BSi} means severe inter-cell interference.

C. Membership Functions

We defined three membership functions to transform the three input metrics to fuzzy sets (Fig. 3a, b, and c). We assumed the transmission power is in range between 25–43 dBm and were calculated *Area Coverage Radius*, which is in range between 1.5–12.0 km, using the FSPL Model [17]. The *Traffic Load* is in range between 0–46 Mbps, this range originated from WiMAX forum experimental results [6]. The *Overlapping Area Rate* has a value between 0 and 1. The *Area Coverage Radius*, *Traffic Load*, and *Overlapping Area Rate* are each divided into three categories; *low*, *medium*, and *high*.

We also defined one output membership function (Fig. 3d) for changing the transmission power. This function has an output value in the range from -0.9 to 0.9 dBm, and is divided into seven categories; *decrease more*, *decrease*, *decrease little*, *do nothing*, *increase little*, *increase*, and *increase more*.

D. Fuzzy Rules

We defined twenty-seven fuzzy rules that are used in the *Rule evaluation* step of Mamdani FIS [14] as follows:

1) IF traffic load IS low AND overlapping area rate IS low AND area coverage radius IS low THEN power level change IS increaseMore;
2) IF traffic load IS low AND overlapping area rate IS low AND area coverage radius IS medium THEN power level change IS increaseMore;
3) IF traffic load IS low AND overlapping area rate IS low

AND area coverage radius IS high THEN power level change IS increase;

4) IF traffic load IS low AND overlapping area rate IS medium AND area coverage radius IS low THEN power level change IS increaseLittle;
5) IF traffic load IS low AND overlapping area rate IS medium AND area coverage radius IS medium THEN power level change IS doNothing;
6) IF traffic load IS low AND overlapping area rate IS medium AND area coverage radius IS high THEN power level change IS doNothing;
7) IF traffic load IS low AND overlapping area rate IS high AND area coverage radius IS low THEN power level change IS decreaseLittle;
8) IF traffic load IS low AND overlapping area rate IS high AND area coverage radius IS medium THEN power level change IS decrease;
9) IF traffic load IS low AND overlapping area rate IS high AND area coverage radius IS high THEN power level change IS decreaseMore;
10) IF traffic load IS medium AND overlapping area rate IS low AND area coverage radius IS low THEN power level change IS increase;
11) IF traffic load IS medium AND overlapping area rate IS low AND area coverage radius IS medium THEN power level change IS increaseLittle;
12) IF traffic load IS medium AND overlapping area rate IS low AND area coverage radius IS high THEN power level change IS increaseLittle;
13) IF traffic load IS medium AND overlapping area rate IS medium AND area coverage radius IS low THEN power level change IS increaseLittle;
14) IF traffic load IS medium AND overlapping area rate IS medium AND area coverage radius IS medium THEN power level change IS doNothing;
15) IF traffic load IS medium AND overlapping area rate IS medium AND area coverage radius IS high THEN power level change IS doNothing;
16) IF traffic load IS medium AND overlapping area rate IS high AND area coverage radius IS low THEN power level change IS decreaseLittle;
17) IF traffic load IS medium AND overlapping area rate IS high AND area coverage radius IS medium THEN power level change IS decrease;
18) IF traffic load IS medium AND overlapping area rate IS high AND area coverage radius IS high THEN power level change IS decreaseMore;
19) IF traffic load IS high AND overlapping area rate IS low AND area coverage radius IS low THEN power level change IS decreaseLittle;
20) IF traffic load IS high AND overlapping area rate IS low AND area coverage radius IS medium THEN power level change IS decrease;
21) IF traffic load IS high AND overlapping area rate IS low AND area coverage radius IS high THEN power level change IS decrease;
22) IF traffic load IS high AND overlapping area rate IS medium AND area coverage radius IS low THEN power level change IS decreaseLittle;
23) IF traffic load IS high AND overlapping area rate IS medium AND area coverage radius IS medium THEN power level change IS decrease;
24) IF traffic load IS high AND overlapping area rate IS medium AND area coverage radius IS high THEN power level change IS decrease;
25) IF traffic load IS high AND overlapping area rate IS high AND area coverage radius IS low THEN power level change IS decrease;
26) IF traffic load IS high AND overlapping area rate IS high AND area coverage radius IS medium THEN power level change IS decreaseMore;
27) IF traffic load IS high AND overlaping area rate IS high AND area coverage radius IS high THEN power level change IS decreaseMore.

TABLE I
SIMULATION PARAMETERS FOR MOBILE MIMAX

Parameter	Value	Parameter	Value
Frequency Reuse Pattern	1x1x1	Transmit Power Range	25–43 dBm
Peak Data Rate	46 Mbps	Operating Frequency	2500 MHz
BS Antenna Gain	15 dBi	MS Antenna Gain	-1 dBi
MS Sensitivity	-85 dBm	Miscellaneous Losses	20 dB
Channel Bandwidth	10 MHz	Coding Scheme	OFDMA

IV. SIMULATION ENVIRONMENT

We validated the proposed scheme in the mobile WiMAX [13] simulation environment. The environment was implemented in JAVA. 3GPP LTE-Advanced and IEEE 802.16m are not commercially available yet, so we cannot implement a realistic simulation environment. Instead we chose the mobile WiMAX system, because it uses IEEE 802.16m base technology and features state-of-the-art techniques. Related parameters are described in Table I and we set four assumptions to simplify the simulation model as follows:

- The area coverage follows the FSPL Model [17].
- The downlink versus uplink traffic ratio is 3:1 and a 2×2 MIMO antenna is used, so the maximum downlink bandwidth is 46 Mbps [6].
- We only consider the downlink traffic load.
- The traffic load is distributed following a uniform distribution.

We also made three simulation scenarios to show the validity of our work, and defined six evaluation metrics to evaluate the results numerically.

A. Free Space Path Loss Model

We assumed that the simulation network is in a free space zone without obstacles. For that we used FSPL [17] to relate the transmission power and the area coverage radius. FSPL is the loss of signal strength in free space which means that there are no obstacles to cause reflection or diffraction. FSPL is proportional to the square of the frequency and the square of the distance between the transmitter and the receiver. The basic equation for FSPL is:

$$FSPL = \left(\frac{4\pi df}{c}\right)^2, \tag{3}$$

where f [Hz] is frequency, d [m] is distance between the transmitter and receiver, and c [m/s] is the speed of light in a vacuum.

FSPL also can be expressed in terms of dB:

$$FSPL(dB) = 20\log_{10}(d) + 20\log_{10}(f) - 32.45, \tag{4}$$

where f is measured in MHz and d is measured in km.

Now we can build a link budget using FSPL as follows:

$$P_{RX} = P_{TX} + G_{TX} - L_{TX} - FSPL - L_M + G_{RX} - L_{RX}, \tag{5}$$

where P_{RX} [dBm] is the received power, P_{TX} [dBm] is the transmitter output power, G_{TX} [dBi] is the transmitter antenna gain, L_{TX} [dB] is the transmitter losses, $FSLP$ [dB] is the free space path loss, L_M [dB] is miscellaneous losses, G_{RX} [dBi] is receiver antenna gain, and L_{RX} [dB] is receiver losses.

Combining (4) and (5), and setting P_{RX} as the minimum receiver sensitivity, we can easily obtain the coverage radius from the transmission power.

B. Simulation Scenarios

We made three scenarios to show that the proposed method works well. The BSs were assumed to be optimized by considering the area coverage, traffic load, and interference before each scenario was applied.

- *Scenario 1*: The traffic load was increased in the six BS areas, so it is over the maximum affordable traffic load, i.e., 46 Mbps, of a BS. Consequently, users who are in the coverage area of these BSs cannot be served normally because of system performance degradation. In the proposed method, the BSs are expected to decrease their transmission power to reduce the traffic load to an affordable level, i.e., below 46 Mbps.
- *Scenario 2*: Two BSs are malfunctioning due to a power outage, so users in this area cannot be served normally. The neighboring BSs are expected to increase their transmission power to cover the outage area.
- *Scenario 3*: Three BSs are newly installed in a crowded area or a shadowed area. The overall coverage is increased and the shadow area is decreased, but the interference is increased, because the transmission power is not adjusted among the newly installed BSs and neighboring BSs. The newly installed BSs and neighboring BSs are expected to change their transmission power level to maintain an allowable interference level.

C. Evaluation Metrics

We defined six evaluation metrics to validate the proposed method as follows:

1) Area Coverage Rate (A): This metric represents the rate between the number of covered pixels and the number of total pixels. That is,

$$A = \frac{\sum_{x=1}^{n}\sum_{y=1}^{m} p(x,y)}{n \cdot m}, \tag{6}$$

where $p(x,y)$ is a function that indicates whether a pixel (x,y) is covered or not, i.e., 0 if not covered and 1 if covered. A high *Area Coverage Rate* is preferred.

2) Traffic Coverage Rate (T): This metric represents the rate between the covered traffic load and total traffic load. That is:

$$T = \frac{\sum_{x=1}^{n}\sum_{y=1}^{m} \delta(x,y) \cdot p(x,y)}{\sum_{x=1}^{n}\sum_{y=1}^{m} \delta(x,y)}, \tag{7}$$

where $\delta(x,y)$ is the traffic load at pixel (x,y). A high *Traffic Coverage Rate* is preferred.

3) Total Overlapping Area Rate (O): This metric is defined as rate between the total number of overlapping pixels and the total number of covered pixels. That is:

$$O = \frac{\sum_{x=1}^{n}\sum_{y=1}^{m} \omega(x,y)}{\sum_{x=1}^{n}\sum_{y=1}^{m} p(x,y)}, \tag{8}$$

where $\omega(x,y)$ is a function that indicates whether a pixel (x,y) is covered by more than two BSs or not, i.e., 1 if covered by more than two BSs and 0 if covered by only one BS or not covered. A low *Total Overlapping Area Rate* is preferred.

4) Power Consumption Rate (P): The *Power Consumption Rate* is defined as the rate between the total current transmission power and the total maximum transmission power. That is:

$$P = \frac{\sum_{i=1}^{k} PL_{BSi}}{k \cdot PL_{max}}, \tag{9}$$

where k is a number of whole BSs, PL_{max} is the maximum transmission power of one BS, and PL_{BSi} is the current transmission power of the BS i. A low *Power Consumption Rate* is preferred.

5) Overall Rate (R): We defined the *Overall Rate* to show four evaluation metrics, i.e., *Area Coverage Rate*, *Traffic Coverage Rate*, *Total Overlapping Area Rate*, and *Power Consumption Rate* as one metric as follows:

$$R = \alpha_1 \cdot A + \alpha_2 \cdot T + \alpha_3 \cdot (1 - O) + \alpha_4 \cdot (1 - P), \tag{10}$$

where α_i is a weight value, and the sum of all α_i should be equal to 1. We assumed that all α_i values are the same, i.e., α_i = 0.25. The *Total Overlapping Area Rate* and *Power Consumption Rate* are subtracted from 1, because low values

TABLE II
SIMULATION RESULTS FOR EACH SCENARIO

	Scenario 1		Scenario 2		Scenario 3	
	Fixed	**Fuzzy logic**	**Fixed**	**Fuzzy logic**	**Fixed**	**Fuzzy Logic**
Area Coverage Rate	0.915	0.834	0.839	0.884	0.947	0.930
Traffic Coverage Rate	0.935	0.875	0.843	0.888	0.942	0.925
Total Overlapping Area Rate	0.142	0.133	0.125	0.120	0.237	0.145
Power Consumption Rate	0.703	0.682	0.701	0.704	0.705	0.692
Overall Rate	0.751	0.723	0.714	0.737	0.737	0.755
Congested BSs	5.400	0.000	0.000	0.000	0.000	0.000

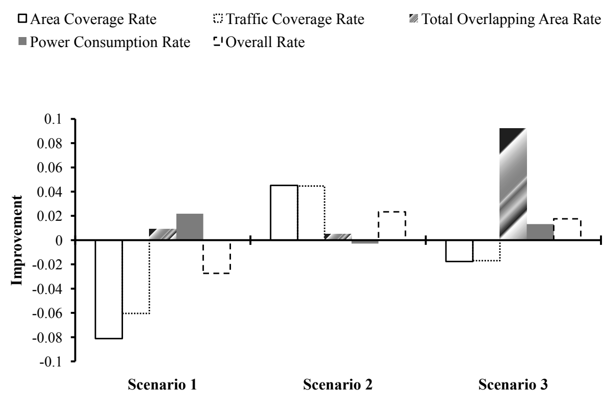

Fig. 4. Improvements of the five evaluation metrics for each scenario.

are preferred for these metrics. A high *Overall Rate* is preferred.

6) Congested BSs (C): The *Congested BSs* is the number of BSs that have a traffic load larger than the maximum affordable traffic load, which is set to 46 Mbps in this article. A low *Congested BSs* is preferred.

V. SIMULATION RESULTS

For each scenario, the simulation was done five times. There were two schemes compared in the simulations, including a fixed transmission power scheme, and the proposed scheme that autonomously changes the transmission power using the previously defined fuzzy logic controllers. Before applying each scenario, we assumed that the BSs were optimized by considering area coverage, traffic load, and interference. We calculated the mean of the results: *Area Coverage Rate*, *Traffic Coverage Rate*, *Total Overlapping Area Rate*, *Power Consumption Rate*, *Overall Rate*, and *Congested BSs* (Table II).

Fig. 4 shows the improvements of all the evaluation metrics except *Congested BSs*. *Area Coverage Rate*, *Traffic Coverage Rate*, and *Overall Rate* improvements are calculated by subtracting the *Fixed* results from the *Fuzzy logic* results. The *Total Overlapping Area Rate* and the *Power Consumption Rate* improvements are calculated by subtracting the *Fuzzy logic* results from the *Fixed* results, because these metrics suggest a good performance when they are close to 0.

For scenario 1, which has an increased traffic load in the six BS areas, the *Area Coverage Rate*, *Traffic Coverage Rate*, and *Overall Rate* diminished, but the *Total Overlapping Area Rate* and *Power Consumption Rate* improved. The *Congested BSs*, the most important metric for this scenario, decreased from 5.4 to 0. This means that the congested BSs reduced their transmission power to change the traffic load to an affordable level.

We assumed that congested BSs serve the users normally, because there is no exact model to describe congested situations. For this reason, the *Traffic Coverage Rate* diminished in the proposed method. In a real situation, however, the congested BSs cannot support the maximum traffic load, so we expect that the *Traffic Coverage Rate* would improve in the *Fuzzy logic* scheme, if we use our method in the real environment. In addition to the above, other parameters that were not considered in this simulation including user satisfaction and voice call quality would also improve.

In scenario 2, which was in an outage situation, all the evaluation metrics improved except the *Power Consumption Rate*. This means that the neighboring BSs autonomously increased their transmission power to cover the outage area.

Finally in scenario 3, which had three newly installed BSs, the *Total Overlapping Area Rate*, *Power Consumption Rate*, and *Overall Rate* improved, whereas the *Area Coverage Rate* and *Traffic Coverage Rate* diminished. This means that the newly installed BSs and neighboring BSs changed their transmission power to maintain an acceptable interference level. Therefore the *Overall Rate* improved, even though the *Area Coverage Rate* and *Traffic Coverage Rate* diminished.

VI. CONCLUSIONS AND FUTURE WORK

Taking into account the complexity of the Mobile WiMAX network is very important as the system requires fine tuning to cope with changing situations. The SON concept, which aims to provide the network with inner mechanisms that allow it to self-organize, is very important. In this research, we proposed a SON solution using fuzzy logic. This is motivated by the fact that the environment is very complex and the fuzzy logic technique has been successfully used in other complex systems. To achieve this, we defined three input metrics, i.e., the *Area Coverage Radius*, *Traffic Load*, and *Overlapping Area Rate*, and defined membership functions for each input metric. We also defined fuzzy rules that evaluate the input metrics and change the transmission power dynamically. We implemented this in a mobile WiMAX simulation environment, and validated the proposed method in three different scenarios.

Six evaluation metrics were defined to evaluate the results numerically.The simulation results showed that the proposed scheme can provide flexibility and improve on the coverage area and overall performance of a mobile network system.

For future research, we plan to consider more input parameters, including frequency channel and upload traffic load, in addition to the parameters covered here; *Area Coverage Radius*, *Download Traffic Load*, and *Overlapping Area Rate*. Moreover, optimization of the membership functions and fuzzy rules will also be taken into consideration to obtain an optimal performance level. We will use a realistic statistical propagation model for simulation to elaborate obstacles and mobility which were ignored in this article.

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