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Self-organizing and Self-healing Mechanisms in Cooperative Small-cell Networks

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***Abstract*—Small-cell networks are expected as one of key solutions for high system capacity. However, self-organizing and self-healing mechanisms are necessarily required to deploy and manage an increasing number of small-cell networks. In this paper, we consider a future small-cell network as an intelligent distributed antenna system such as an adaptive array antenna. We propose a self-organizing mechanism and a self-healing mechanism for small-cell networks through cooperative clusters. We evaluate the system performance in terms of resource utilization in both normal and failure cases of a small-cell network. The results show that proposed mechanisms outperform the conventional mechanisms.**

I. Introduction

Future wireless communication networks will aim at providing users with high data rate services. The demand for high data rates has triggered new technologies, such as mobile Worldwide Interoperability for Microwave Access (mobile WiMAX) [1] and Long Term Evolution-Advanced (LTE-A) [2]. In parallel, small-cell networks overlaid on an existing macro-cell network have been in progress in LTE-A release 10-12 [3].

Especially, since small-cell networks significantly increase system capacity with lower transmit power, deployment of small-cell networks has attracted attention in recent days. Leem *et al.* [4] showed that deploying small-cell networks is a very effective solution to accommodate high data rates with low energy consumption in future green radio environments. However, if small-cell networks are densely installed, then it may cause severe inter-cell interference (ICI) to users at cell edges [5]. Bang *et al.* [6] showed an energy-efficient subchannel allocation scheme exploiting a modified fractional frequency reuse (FFR) concept and adaptive cooperative clusters among small-cell networks in order to minimize ICI and maximize capacity.

On the other side, a small-cell network has been considered as a distributed antenna system. Liu *et al.* [7] considered a small-cell network as an omni-directional antenna system, and Wu *et al.* [8] proposed a small-cell network as a sectorized distributed antenna system. Distributed antenna technologies at small-cell networks have evolved from omni-directional antennas to multiple antennas or an adaptive array antenna [9]. Eventually, a small-cell network as an intelligent antenna system will be deployed in future mobile communication networks in order to reduce capital expenditure and energy consumption.

However, in business aspects, deployment of small-cell networks has a limitation in operation and management due to an increasing number of small-cell networks. Furthermore, when a failed small-cell network occurs, it is difficult to satisfy the required quality of service because small-cell networks do not have redundant systems to increase reliability. Thus, a self-healing mechanism without human involvement is obligatorily required to deploy small-cell networks.

Fuqiang *et al.* [10] showed the effect of antenna downtilt as a self-healing mechanism in a macro-cell environment and Amirijoo *et al.* [11] introduced a framework for cell outage management and outlined key components in a macro-cell environment. But, there have been few studies on self-healing mechanisms for small-cell networks.

We here consider a future small-cell network as an adaptive array antenna system with multiple beams, and propose a self-organizing mechanism and a self-healing mechanism in small-cell networks.

The rest of this paper is organized as follows. In Section II, we introduce a new cooperative small-cell network and propose a self-organizing mechanism based on cooperative clusters. In Section III, we propose a three-step self-healing mechanism through re-organizing cooperative clusters. In Section IV, we show a simulation scenario and numerical results. Finally, we present conclusions in Section V.

II. Self-Organizing Mechanism in Cooperative Small-Cell Networks

The concept of a self-organizing network (SON) was introduced in [12]. SON has functions of self-configuration, self-optimization and self-healing. In the self-configuration process, newly deployed small-cell networks are automatically configured from a SON manager. Self-optimization is the process of cooperation and coordination among neighbor cells to mitigate inter-cell interference and enhance capacity. Self-healing process is to detect a failed small-cell network and recover coverage holes automatically through the SON manager. Similar to SON, we propose a new cooperative small-cell networks with an intelligent adaptive array antenna in which a central manager organizes and re-organizes small-cell networks through cooperative clusters.

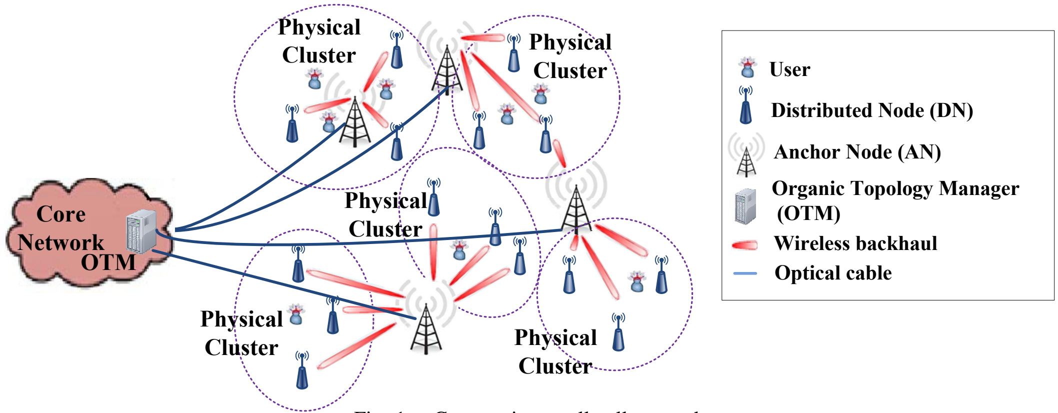

Fig. 1. Cooperative small-cell networks

A. *Network Topology*

We consider a network topology which is composed of a hierarchical set of macro-cell networks and small-cell networks. A macro-cell network and a small-cell network use different sub-channel resource, while small-cell networks reuse allocated all resources (e.g., time, frequency). The components of the network are *distributed nodes (DNs), anchor nodes (ANs), and an organic network topology manager (OTM)*, as shown in Fig. 1. Links between one AN and its DNs are called a back-haul link with high speed and can be configured by a wired link [13] using a passive optical network (PON) or line of sight (LOS)/ non-LOS wireless link [14] using a narrow beam.

DNs provide coverage from several tens of meters to hundreds of meters as small-cell networks (e.g., micro- and pico-cell networks). A DN is an intelligent distributed antenna system such as an adaptive array antenna with multiple beam patterns. In other words, the DN receives beam pattern information, resource allocation information, and routing information from the corresponding AN. The DN radiates beam pattern allocated from the corresponding AN. The gain of the beam pattern from [15] (Eq. (6)) is expressed as:

$$A(\theta) = G_{max} \cdot exp(\frac{-\theta^2}{2 \cdot \theta_m{}^2}), \quad -180^\circ \leq \theta \leq 180^\circ, \tag{1}$$

where θ is the angle between the center of a beam and a user, θ_m is the half power beamwidth of the beam, and G_{max} is the maximum gain.

AN provides coverage from several hundreds of meters to kilo-meters, similar to that of the basestation of a macro-cell network. It has 3-layer functions to manage multiple DNs in its own macro-cell network. Each AN receives the channel information of users from multiple DNs for organizing cooperative clusters and then forwards this control information to the OTM.

OTM manages and controls all ANs and all DNs. Specifically, it determines the beam pattern of each DN, a cooperation mode among DNs, and resource allocation for users. Throughout the process, it selects one of the multiple beams to make cooperative clusters among DNs according to the cell size and the location of a service area. Although OTM performs a centralized mechanism increasing control information, the impact on system performance is not significant due to backhaul link with high speed.

B. *Self-Organizing Cooperative Clusters*

As the number of DNs increases, the interference among DNs may increase due to resource reuse. OTM creates a cooperative cluster among DNs in order to reduce the interference and increase the system capacity. The cooperative cluster is classified into two types: *a physical cluster and a logical cluster*. The physical cluster based on the location information of each DN consists of DNs within a maximum cooperative distance. In contrast, the logical cluster may be dynamically generated, updated, or removed depending on user activity, i.e., each user may be served by one of local clusters which is called the optimal logical cluster. Process from setting up a physical cluster to searching the optimal logical cluster is as follows:

Step 1) Create a physical cluster statically A physical cluster is determined when DN is installed. We set the maximum number of DNs in a physical cluster to three since the energy efficiency in hexagonal small-cell networks is maximized with cooperation of three DNs according to the result in [16]. As shown in the example Fig. 2(a) shows 6 physical clusters each of which consists of three DNs. The beam direction is toward the center of a physical cluster and the beamwidth is set to 60°. Three DNs turn on 60° beam pattern simultaneously in order to serve a physical cluster, therefore, six beam patterns cover the whole area service.

Step 2) Generate logical clusters dynamically Logical clusters are subsets of a physical cluster during sending or receiving data. Fig. 2(b) expresses four local clusters in a physical cluster $\{DN_1, DN_2, DN_3\}$. If the logical cluster consists of multiple DNs, DNs in the logical cluster simultaneously transmit data to a single user in order to achieve transmit diversity gain and power gain.

n and k denote the index of DN and the user's index, respectively. T denotes the set of all DNs and $J_{(n,k)}$ represents all the sets of logical clusters for user k in DN_n and $J_{i(n,k)}$

represents the ith subset of $J_{(n,k)}$. For instance, $J_{(1,k)}$ for user k in the coverage of DN_1 is expressed as:

$$J_{(1,k)} = \{J_{1(1,k)}, J_{2(1,k)}, J_{3(1,k)}, J_{4(1,k)}\},$$
$$where \begin{cases} J_{1(1,k)} = \{DN_1\}, \\ J_{2(1,k)} = \{DN_1, DN_2\}, \\ J_{3(1,k)} = \{DN_1, DN_3\}, \\ J_{4(1,k)} = \{DN_1, DN_2, DN_3\}. \end{cases} \quad (2)$$

If the ith logical cluster $J_{i(n,k)}$ is allocated to user k in DN_n, user k receives the combined power, $P_{RX(J_{i(n,k)},k)}$, from DNs in the ith logical cluster, $J_{i(n,k)}$, and receives interference $I_{(J_{i(n,k)},k)}$ from out of the ith logical cluster. $P_{RX(J_{i(n,k)},k)}$ and $I_{(J_{i(n,k)},k)}$ of user k in the ith logical cluster, $J_{i(n,k)}$, are expressed as:

$$P_{RX(J_{i(n,k)},k)} = \sum_{j \in J_{i(n,k)}} P_{RX(j,k)},$$
$$I_{(J_{i(n,k)},k)} = \sum_{j \in T} P_{RX(j,k)} - \sum_{j \in J_{i(n,k)}} P_{RX(j,k)}, \quad (3)$$

where $P_{RX(j,k)}$ represents the user k's received signal from DN_j.

$SINR_{(J_{i(n,k)},k)}$ denotes the user k's SINR in the ith logical cluster, $J_{i(n,k)}$, and is given by:

$$SINR_{(J_{i(n,k)},k)} = \frac{P_{RX(J_{i(n,k)},k)}}{I_{(J_{i(n,k)},k)} + N_0}. \quad (4)$$

The channel capacity of user k in the ith logical cluster $J_{i(n,k)}$ is related to the bandwidth of a subchannel, B_{sub}, and the $SINR_{(J_{i(n,k)},k)}$ based on Shannon's capacity formula is given by:

$$C_{(J_{i(n,k)},k)} = B_{sub} \cdot \log_2(1 + SINR_{(J_{i(n,k)},k)}). \quad (5)$$

$S_{(J_{i(n,k)},k)}$ denotes the required number of subchannels for user k in the ith logical cluster, $J_{i(n,k)}$, and is calculated as:

$$S_{(J_{i(n,k)},k)} = \frac{R_0}{C_{(J_{i(n,k)},k)}}, \quad (6)$$

where R_0 denotes the required data rate.

Step 3) Select the optimal logical cluster
The optimal logical cluster is the logical cluster with the smallest number of required sub-channels of logical clusters satisfying $SINR_{min}$. Thus, user k's optimal logical cluster, $J^*_{i(n,k)}$, is given by:

$$J^*_{(n,k)} = \arg_{\forall i(n,k)} \min \; S_{(J_{i(n,k)},k)},$$
$$subject\, to \; SINR_{(J_{i(n,k)},k)} \geq SINR_{min}, \quad (7)$$

where $SINR_{min}$ is the minimum SINR to detect the desired signal.

Step 4) Update logical clusters recursively
Logical clusters are frequently changed by a user's several factors, such as user's SINR, user mobility, the required service data rates, and interference. The OTM re-organizes logical clusters through *step 2* and *step 3* during data transmission recursively.

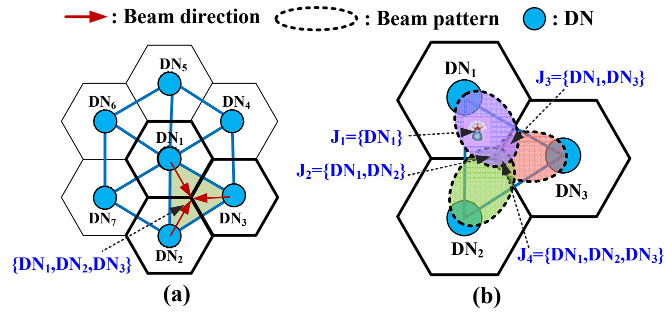

Fig. 2. Two types of cooperative clusters (a) a physical cluster (b) four logical clusters in a physical cluster

III. Self-Healing Mechanism in Cooperative Small-Cell Networks

OTM checks the link status of DNs through an event-driven method or periodic monitoring. When a failed DN occurs, the OTM detects the failed DN and re-organizes physical clusters including the failed DN. The OTM requests an AN to update the information of physical clusters including the failed DN in order to recover the failed region and then the AN forwards control information on updated physical clusters to the corresponding DNs. Finally, DNs adjust a cooperation mode and beam pattern to updated the physical clusters. After physical clusters are reconfigured, logical clusters are re-organized based on user's activity. Therefore, the three-step self-healing mechanism performs to reconfigure physical clusters according to the following three-step processes as:

Step 1. The OTM selects neighbor DNs within a given cooperative distance from the failed DN as the members of a new physical cluster.

Step 2. Adjust the direction of beam, θ_0, of all DNs in the new physical cluster toward the failed DN and the beamwidth, ω, by considering the location information of neighbor DNs in the new physical cluster.

Step 3. Adjust the transmit power of DNs in the new physical cluster applying new θ_0 and ω.

For example, Fig. 3 shows the self-healing process. In *Step 1*, when the center DN in the first tier fails as shown in Fig. 3(a), six DNs with the same cooperative distance from the failed DN become the members of the new physical cluster. In the case of Fig. 3(b), when two adjacent DNs fail, two new physical clusters are created and each new physical cluster consists of five DNs with the same cooperative distance from the failed DN. In *Step 2*, when the beam forming is set to the direction of the failed DN, the signal power is transmitted toward the failed region. ω is the angle between neighbor DNs and is calculated as the angular distance between the half power points θ_m. In *Step 3*, antenna gain, $A(\theta')$, is adjusted by applying new θ_0 and ω. The estimated transmit power of DNs, P'_{TX}, is given by:

$$P'_{TX} = \frac{P_{RX_{req}} \cdot 10^{0.1 \cdot PL}}{10^{0.1 \cdot A(\theta')}}, \quad (8)$$

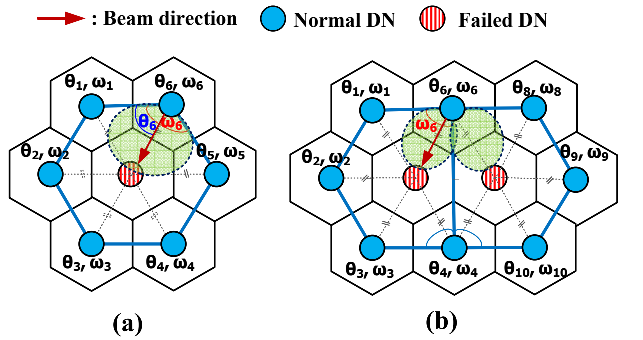

Fig. 3. Self-healing mechanisms (a) a new physical cluster with six DNs (b) two new physical clusters with five DNs

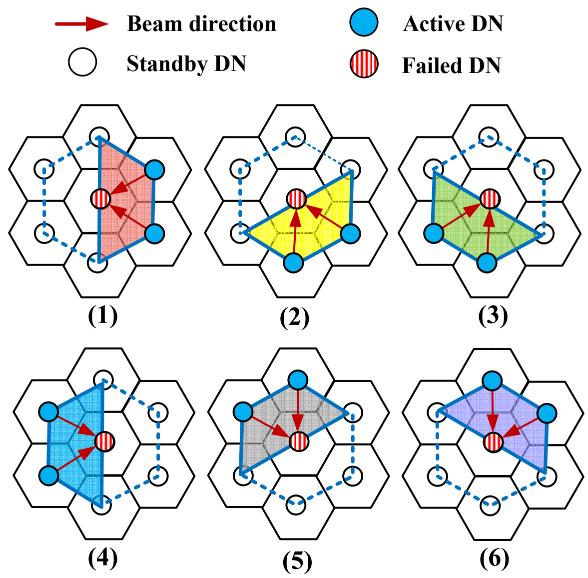

Fig. 4. Cluster scheduling after self-healing mechanism

where $P_{RX_{req}}$ is the required received power, PL is path loss, and θ' is the angle between θ_0 and a user.

When six DNs surrounding a failed DN become the members of a new physical cluster as shown in Fig. 4, the subsets of the physical cluster are scheduled as color sequences: red (1), yellow (2), green (3), blue (4), grey (5), and violet (6). Since cluster scheduling is kept to six times, self-healing mechanisms do not affect the scheduling of neighbor physical clusters without a failed DN.

IV. Performance Evaluation

We consider that the path loss model of DN is based on the outdoor model of a small-cell network in [5]. A cooperation scheme is considered in a downlink environment with the simulation parameters in Table I.

The reference model is based on the cooperative DNs with an omni-directional antenna, while the proposed model is based on cooperative DNs with an adaptive array antenna. When a failed DN occurs, the conventional self-healing mechanism adjusts the antenna transmit power without updating physical clusters. In contrast, the proposed three-step self-healing mechanism re-organizes physical clusters.

Figs. 5(a) and (b) show the failure case and the recovery case in the reference model, respectively. The conventional self-healing mechanism in the reference model shows that the transmit power radiated without adjusting beam patterns causes downlink interference to other cells or users in other cells. In the proposed model, Figs. 5(c), (d), and (e) show the failure case, the recovery case by the conventional self-healing mechanism, and the recovery case by the proposed three-step self-healing mechanism, respectively. Fig. 5(d) shows that the entire failure region is not fully recovered, while Fig. 5(e) shows that the entire failure region is almost recovered by re-organizing the physical clusters and rotating the beam toward the failed DN.

Resource utilization is the ratio of the number of used subchannels N_{used} to the total number of subchannels N_{total}. Fig. 6 shows the resource utilization in a DN with initial transmit power in a normal condition and the resource utilization in a failed DN condition. In the normal condition, the reference model uses the entire resources, while the proposed model uses 38% of the total resources for accommodating 100 users. In a failure condition, the reference model accommodates 28 users, while the proposed model accommodates 60 users with the total resources. Thus, the proposed model improves resource utilization by 2.6 times in the normal condition and by 2.1 times in a failure condition, compared with that of the reference model.

Fig. 7 shows the resource utilization in a failed DN when DNs in physical clusters including a failed DN increase up to the maximum transmit power in order to recover the communication for users in a failed DN. The reference model can accommodate 32 users, while the proposed model with the conventional self-healing mechanism can accommodate 110 users with the total resources. The proposed model with the conventional self-healing mechanism achieves 3.4 times higher resource utilization, compared with that of the reference model. The proposed model with the proposed three-step self-healing mechanism yields two times higher resource utilization, compared with that of the proposed model with the conventional self-healing mechanism.

Fig. 8 shows the resource utilization in a failed DN for the proposed three-step self-healing mechanism and the conventional self-healing mechanism in the proposed model during 13 unit times and a given simulation scenario is as follows:

- T_1 - T_2 : All DNs operate normally with initial transmit power.
- T_3 : A failed DN occurs at T_3. (Refer to Fig. 5(a) and (c).)
- T_4 - T_{13} : Recovery is performed from T_4 to T_{13}. (Refer to Figs. 5(b), (d), and (e), while the transmit power increases 20% per unit time.)

In Fig. 8, the proposed model utilizes 24% of the total resources for accommodating 60 users in a normal condition. When a DN fails, the total resources of the DN are used for accommodating 60 users. As the transmit power of DNs

TABLE I
SIMULATION PARAMETERS

Parameters	Values
Radius of DNs	100[meter]
The number of cells	7[cells]
Initial/Max. Tx power of DNs	50,150[mW]
Max. antenna gain (G_{max})	0(omni),3(120° beam), 6(60° beam)[dB]
The bandwidth of system	10[MHz]
The bandwidth of 1 subchannel (B_{sub})	30×9.765[kHz]
Minimum SINR ($SINR_{min}$)	-2, 0[dB]
The required data rate (R_0)	2[Mbps]
The half power beamwidth (θ_m)	35°(60° beam) 70°(120° beam) [17]

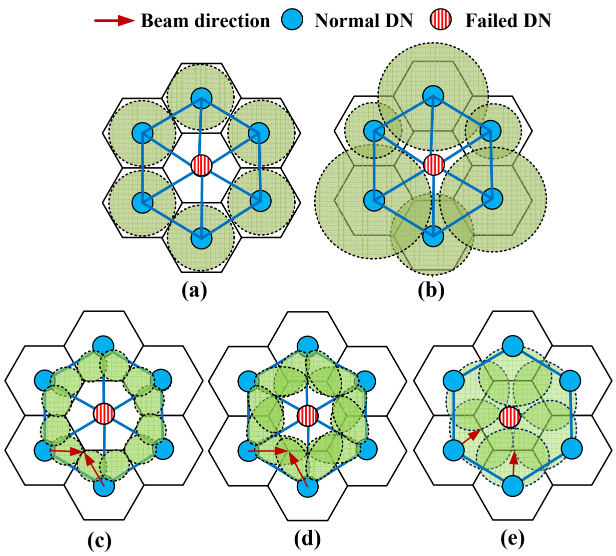

Fig. 5. Failure and recovery cases when a failed DN occurs (a) failure case in the reference model (b) recovery case in the reference model (c) failure case in the proposed model (d) recovery case with the conventional self-healing mechanism in the proposed model (e) recovery case with the proposed three-step self-healing mechanism in the proposed model

increases, the resource utilization decreases due to improved SINR. When the members of physical clusters increase up to maximum transmit power at T_{13}, the conventional self-healing mechanism utilizes 56% of the total resources, while the proposed three-step self-healing mechanism utilizes 28% of the total resources for accommodating 60 users.

V. CONCLUSIONS

A small-cell network has been proposed as a key solution to accommodate growing wireless traffic. In general, it is a low cost network without redundant functions for system reliability. In addition, an increasing number of small-cell networks may cause a difficulty in operation and management. Hence, a self-organizing mechanism and a self-healing mechanism without human involvement are necessarily required to deploy the small-cell networks. In this paper, we considered a

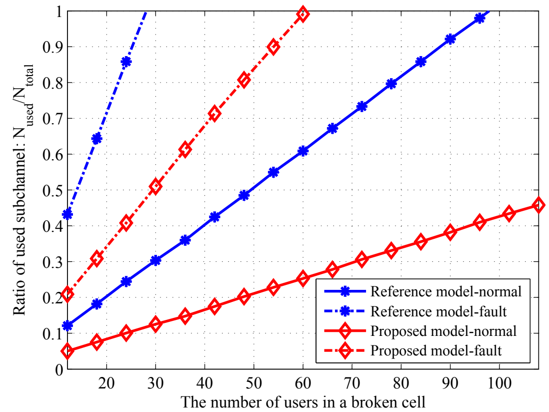

Fig. 6. Resource utilization in a DN with in a normal condition and resource utilization in a failed DN in a failure condition

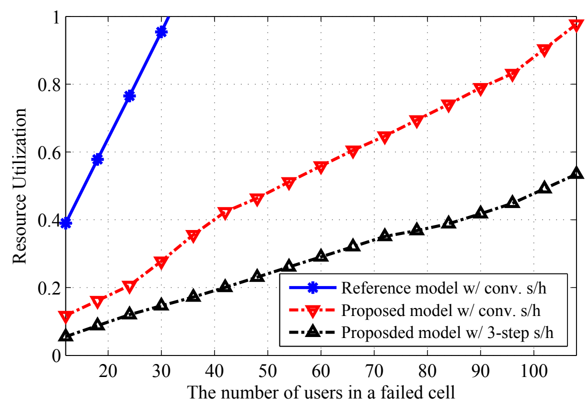

Fig. 7. Resource utilization in a failed DN in a recovery condition

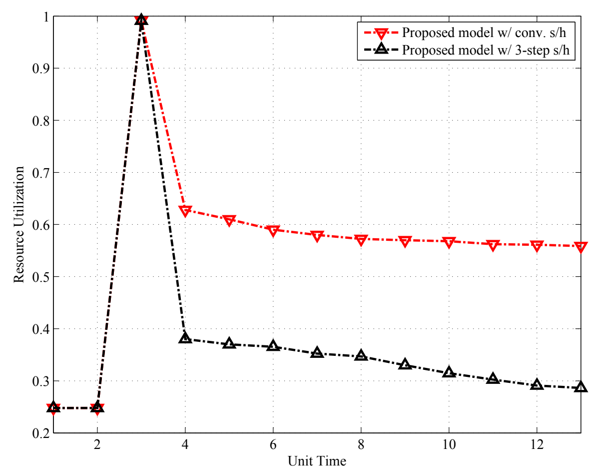

Fig. 8. Resource utilization in a failed DN by the conventional self-healing mechanism and the proposed three-step self-healing mechanism according to a given simulation scenario

future small-cell network as an adaptive array antenna system with multiple beams, and proposed a self-organizing mechanism and a three-step self-healing mechanism for small-cell networks through cooperative clusters. In the self-organizing mechanism, the network manager determines physical clusters and logical clusters among small-cell networks to maximize resource utilization and increase system capacity. In the self-healing mechanism, the network manager re-organizes physical clusters including a failed small-cell network. From our numerical results, the proposed mechanisms yields 2.6 times higher resource utilization in a normal condition and 2.1 times higher resource utilization in a failure condition, compared with that of the conventional mechanisms.

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REFERENCES

[1] WiMAX Forum, "Mobile WiMAX - Part I: A technical overview and performance evaluation", 2006.

[2] 3GPP TS36.300 V9.0.0, "Evolved universal terrestrial radio access (E-UTRA) and evolved universal terrestrial radio access network (EU-TRAN); Overall description; Stage 2", 2009.

[3] 3GPP TS 36.300 V11.5.0, "Technical Specification Group Radio Access Network; E-UTRA and E-UTRAN; Overall description; Stage 2 (Release 11)", 2013.

[4] H. Leem, S.Y. Baek, and D.K. Sung, "The effects of cell size on energy saving, system capacity, and per-energy capacity", *IEEE WCNC*, 2010.

[5] C. Lima, M.Bennis, K. Ghaboosi, and M. Latva-aho, "Interference management for self-organized femtocells towards green networks", *IEEE PIMRC*, 2010.

[6] I.K. Bang, S.H. Kim, S.M. Kim, and D.K. Sung, "Energy-efficient subchannel allocation scheme based on adaptive base station cooperation in downlink cellular networks", *IEEE WCNC*, 2011.

[7] Z. Liu, T. Kolding, P. Mogensen, B. Vejgaard, and T. Sorensen, "Economical comparison of enterprise in-building wireless solutions using DAS and Femto", *IEEE VTC Fall*, 2012.

[8] T. Wu, Y.H. Kwon, J. Zhang, and, Y. Wang, "Distributed antenna systems with power adjusted beam switching", *IEEE VTC Fall*, 2010

[9] K. Ramachandran, R. Kokku, K. Sundaresan, M. Gruteser, and S. Rangarajan, "R2D2: Regulating beam shape and rate as directionality meets diversity", *Proceeding MobiSys Proceedings of the 7th international conference on Mobile systems, applications, and service*, 2009.

[10] L. Fuqiang, Q. Xuesong, W. Honglin, and M. Luoming, "Adjusting electrical downtilt based mechanism of automatic cell outage compensation", *IEEE International Conference on Communication Technology and Application*, 2011.

[11] M. Amirijoo, L. Jorguseski, T.Kurner, R. Litjens, M. Neuland, L. Schmelz, and U. Turke, "Cell outage management in LTE networks", *IEEE Wireless Communication Systems (ISWCS)*, 2009.

[12] 3GPP TS 36.902, "Self-configuration and self-optimization network use cases and solutions".

[13] M. Portolan, "Packet-based JTAG for remote testing", *IEEE International Test Conference (ITC)*, 2012.

[14] M. Coldrey, H. Koorapaty, J.E. Berg, Z. Ghebretensae, J. Hansryd, A. Derneryd, and S. Falahati, "Small-cell wireless backhauling: a non-line-of-sight approach for point-to-point microwave links", *IEEE VTC Fall*, 2012.

[15] V. Namboodiri, L. Gao, and R. Janaswamy, "Power efficient topology control for wireless networks with wwitched beam directional antennas", *IEEE Mobile Adhoc and Sensor Systems Conference*, 2005.

[16] A. J. Fehske, P. Marsch, and G. P. Fettweis, "Bit per joule efficiency of cooperating base stations in cellular networks", *IEEE GLOBECOM*, 2010.

[17] S. Sesia, I. Toufic, and M. Baker, "*LTE-The UMTS Long Term Evolution : From Theory to Practice, p488*", Chichester, U.K. Wiley, 2009.