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Research Article

R^2S: Radio Resource Sharing for Wireless Network Reliability in Internet of Things

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Internet of Things is a system where people and things with unique identifiers are connected and able to interact with each other over a network without external intervention. To connect things anytime, network reliability is one of the main requirements for the Internet of Things, in which continuous service can be provided to nodes even in the event of a sudden network failure. To serve consistent quality of service for nodes in any case, we propose a radio resource sharing (R^2S) method which consists of scheduling and power allocation using an optimization method. By evaluating performances with respect to average cell capacity and outage probability in simulations, we show that the R^2S algorithm can solve a coverage hole problem efficiently in Internet of Things.

1. Introduction

The Internet of Things (IoT) is essentially a system of connected things outfitted with data-collecting and data-processing technologies so that those things can interact and communicate among themselves and with the environment [1, 2]. In the IoT, people and things (e.g., RFID tags, sensors, actuators, machine-to-machine devices, and mobile phones) might be connected anytime, anyplace, with anything and anyone. There are several application domains which will be impacted by the emerging IoT such as city administration, education, healthcare, public safety, real estate, and transportation.

In the emerging IoT for the next decade, a new paradigm shift is required to deal with challenges on explosively growing requirements in mobile data traffic volume (1000x), number of connected devices (10~100x), typical end user data rate (10~100x), device/network lifetime (10x), and reduced end-to-end latency (5x) [3]. In order to accommodate these demands, next generation 5G mobile and wireless communication systems need to be further evolved based on fundamental and innovative rethinking of the conventional mobile and wireless communication systems. Although the current 4G systems have been successfully evolving to fulfill current demands up to now, satisfying all the new requirements is still beyond their capacity such as stringent latency, traffic volume density, and reliability. Accordingly, we focus on this new 5G requirement, *reliability*, in this paper.

In the 3GPP long term evolution, a self-organizing network (SON) is a promising technology that can provide a set of automated mechanisms, including self-configuration, self-optimization, and self-healing [4, 5]. In the case of dynamic removal and installation of an indoor base station (IBS) or its failure, nodes can experience discontinuity in the service. Therefore, self-healing is an important issue to deal with network failures automatically, thereby providing customers with reliable communication services in the 3GPP-LTE system. The processes for managing network failure can be divided into three phases, namely, failure detection, diagnosis, and recovery [6]. However, previous studies have tended to focus on the accuracy of failure detection and diagnosis [6–8], rather than methods for repairing failures.

In order to provide reliable communication services for all users, [9] proposed a cooperative beamforming based self-healing algorithm. This centralized algorithm could resolve the network failure effectively. However unrealistic perfect

synchronization, the enormous amount of messages passing, and high computational complexity among base stations are required to operate this algorithm. In [10], a newly defined healing channel and a heuristic resource allocation algorithm based on an opportunistic base station selection were proposed to resolve the abrupt network fault. Because this algorithm utilized an equal power allocation, the network throughput was degraded remarkably as the price for repairing network failure although it could be operated simply. Also, the SOCRATES project under the 7th Framework Program (FP7) proposed a centralized framework for cell outage management in [11, 12]. It consists of cell outage detection with continuous and event-triggered measurements and cell outage compensation (COC) based on adjustment of control parameters such as downlink power, uplink interference level, and antenna tilt. However, COC is basically proposed for the macrocell-type environment, so it is difficult to directly apply to indoor communication systems.

In case of a classical handover algorithm utilized in current wireless communication systems, the nodes in faulty indoor cells (F-nodes) whose SINR value is less than a handover threshold cannot have access to other normal IBSs any more because the normal IBSs do not utilize any algorithms to serve the F-nodes especially. As a result, the F-nodes have difficulty in receiving a continuous service. This motivates us to investigate the research for the wireless network reliability.

In this paper, we propose a method of maintaining quality of service (QoS) for nodes in the event of a sudden network failure, via a radio resource sharing (R^2S) algorithm in OFDMA-based (orthogonal frequency-division multiple accessing) indoor communication systems. The R^2S algorithm consists of scheduling and power allocation, which is found using an optimization technique: (i) In scheduling, each IBS assigns subchannels to the node which can achieve the largest rate among nodes which cannot satisfy QoS preferentially. Since IBSs consider F-nodes as well as their own nodes for scheduling, F-nodes can be also served by one of the normal IBSs, which is called a generous IBS (G-IBS). (ii) In power allocation, each IBS takes account of interference that it causes to the others in accordance with the maximization of system throughput. At the same time, IBSs adjust allocated power by controlling Lagrangian multiplier to guarantee QoS for nodes.

Our main contributions can be summarized as follows:

(i) It is important to serve nodes in faulty cells without degrading the service quality of the nodes included in normal cells. Thus, we propose a practical self-healing algorithm for improving wireless network reliability in consideration of the satisfaction of all nodes in the indoor wireless communications systems.

(ii) We reformulate the original problem, a mixed binary integer, and nonconvex problem, as a tractable form, and find the suboptimal solution for scheduling and power allocation by using an optimization technique. Based on the obtained solution, we propose the R^2S algorithm based on an iterative method.

(iii) We demonstrate that the R^2S algorithm reliably supports nodes in faulty cells as well as normal cells through intensive simulations, thereby improving average cell capacity and reducing outage probability simultaneously.

The remainder of the paper is organized as follows. In Section 2, we describe OFDMA-based indoor IoT system. In Section 3, we propose a radio resource sharing algorithm. In Section 4, the performances of the proposed algorithm are evaluated. Finally, we make conclusions in Section 5.

2. System Model

We consider OFDMA-based indoor IoT systems in which some nodes cannot be served due to the failure of the IBS, as shown in Figure 1. If the operation of the IBS is failed suddenly, the nodes covered by that IBS cannot be served any more. When the IBS is disabled, a centralized cloud operator (CCO) becomes aware of the fault by simple signaling based on the Simple Network Management Protocol (SNMP), because the disabled IBS cannot send any message or report on its status. Nodes whose connection is terminated abnormally can find the preamble or pilot of nearby IBSs. Based on the detected signals from normal IBSs, F-nodes can access one of the normal IBSs.

We assume the following. (i) There are N subchannels in each cell, each of which is used by just one node. Thus, there exists intercell interference. (ii) Information on instantaneous channel quality can be acquired perfectly at IBSs. (iii) Nodes in indoor cells are stationary or move slowly [13]; thus channel quality does not vary during the transmission of a packet. (iv) Interference from a macrobase station (MBS) is dominated by path loss, so the fast-fading effect on subchannels is negligible. Therefore, the interference from the MBS is considered as additive white Gaussian noise (AWGN). We use the following parameters to describe the system model.

(i) $\mathbb{M}$, $\mathbb{M}_N$, and $\mathbb{M}_F$ are a set of total, normal, and faulty cells, respectively. Consider $\mathbb{M} \triangleq \mathbb{M}_N \cup \mathbb{M}_F$. Let $|\mathbb{M}| = M$, $|\mathbb{M}_N| = M_N$, and $|\mathbb{M}_F| = M_F$.

(ii) $\mathbb{N}$ is a set of total subchannels. Let $|\mathbb{N}| = N$.

(iii) $\mathbb{S}$, $\mathbb{S}_m$, and $\mathbb{S}_{\mathbb{M}_F}$ are a set of total nodes, a set of nodes in a cell m, and a set of nodes in faulty cells. Consider $\mathbb{S} \triangleq \mathbb{S}_1 \cup \cdots \cup \mathbb{S}_M$ and $\mathbb{S}_{\mathbb{M}_F} \subset \mathbb{S}$. Let $|\mathbb{S}| = S$, $|\mathbb{S}_m| = S_m$, and $|\mathbb{S}_{\mathbb{M}_F}| = S_{M_F}$.

(iv) $r_{\min}$ is required rate for node to satisfy the quality of service.

(v) $\rho_{m,s}^{[n]}$ and $\vec{\rho}$ are channel assignment indicator whether an IBS m assigns a subchannel n to a node s or not and the set of $\rho_{m,s}^{[n]}$ for $\forall n, s, m$.

(vi) $p_m^{[n]}$ and $\vec{p}$ are allocated power for a subchannel n in a cell m and the set of $p_m^{[n]}$ for $\forall n, m$.

(vii) $p_{\max}$ is maximum power allocated to IBSs.

(viii) $|h_{m,s}^{[n]}|^2$ is channel gain of a subchannel n between a node s and an IBS m.

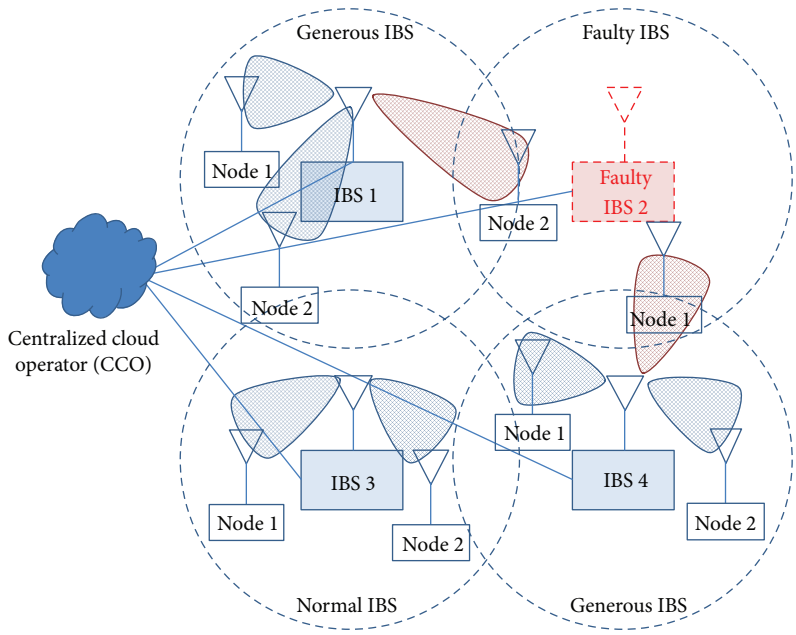

FIGURE 1: System model of OFDMA-based indoor IoT systems.

When node s is served by IBS m through subchannel n, its data rate is written as

$$r_{m,s}^{[n]} = \log_2\left(1+\gamma_{m,s}^{[n]}\right). \tag{1}$$

Also, the signal to interference and noise ratio (SINR), $\gamma_{m,s}^{[n]}$, can be expressed as

$$\gamma_{m,s}^{[n]} = \frac{p_m^{[n]}\left|h_{m,s}^{[n]}\right|^2}{\sigma^2+\sum_{j\in\mathbb{M}_N, j\neq m} p_j^{[n]}\left|h_{j,s}^{[n]}\right|^2} = \frac{p_m^{[n]}\left|h_{m,s}^{[n]}\right|^2}{\sigma^2+I_{m,s}^{[n]}}. \tag{2}$$

Here, $I_{m,s}^{[n]}$ is the total interference on subchannel n experienced by node s served by IBS m and σ^2 contains the effect of interference from the MBS as well as AWGN. Then, the optimization problem whose objective is to maximize system throughput can be formulated as follows:

$$\begin{aligned}
\max_{\vec{p}\geq 0,\vec{\rho}} \quad & \sum_{m\in\mathbb{M}_N}\sum_{s\in\mathbb{S}}\sum_{n\in\mathbb{N}} \rho_{m,s}^{[n]} r_{m,s}^{[n]} \\
\text{s.t.} \quad & \text{C1: } \sum_{n\in\mathbb{N}} \rho_{m,s}^{[n]} r_{m,s}^{[n]} \geq r_{\min} \quad \text{for } s\in\mathbb{S},\ m\in\mathbb{M}_N \\
& \text{C2: } \rho_{m,s}^{[n]} \in \{0,1\}, \quad \text{for } \forall n,s,m \\
& \text{C3: } \sum_{s\in\mathbb{S}} \rho_{m,s}^{[n]} = 1 \quad \text{for } n\in\mathbb{N},\ m\in\mathbb{M}_N \\
& \text{C4: } \sum_{n\in\mathbb{N}} p_m^{[n]} \leq p_{\max} \quad \text{for } m\in\mathbb{M}_N.
\end{aligned} \tag{3}$$

Here, $\vec{p}\geq 0$ means that all elements of $\vec{p}$ are greater than or equal to 0. In (3), F-nodes as well as normal nodes are considered for maintaining reliability when IBSs perform a resource allocation. Constraint C1 assures that all nodes including F-nodes need to be served with at least the required data rate. In constraint C2, if IBS m assigns subchannel n to node s, $\rho_{m,s}^{[n]}=1$. Otherwise, $\rho_{m,s}^{[n]}=0$. Constraint C3 indicates that each subchannel is assigned to only one node. Constraint C4 limits the available transmitting power of IBSs by $p_{\max}$.

3. R^{2}S: A Radio Resource Sharing for Wireless Network Reliability

We relax the constraint C2 by allowing $\rho_{m,s}^{[n]}$ to be a real value, such as $0\leq\rho_{m,s}^{[n]}\leq 1$, since (3) is a mixed binary integer and nonconvex problem. However, it is nondeterministic polynomial-time (NP) hard to find a global optimal solution because of its nonconvexity. Therefore, we propose an iterative resource allocation algorithm that can be implemented in a centralized manner to find the suboptimal solution efficiently. To find scheduling and power allocation strategy, we consider the Lagrangian function of (3) as in

$$\begin{aligned}
&\mathscr{L}\left(\vec{p},\vec{\rho},\vec{\mu},\vec{\nu},\vec{\lambda}\right) \\
&\quad\triangleq \sum_{m\in\mathbb{M}_N}\sum_{s\in\mathbb{S}}\sum_{n\in\mathbb{N}} \rho_{m,s}^{[n]} r_{m,s}^{[n]} \\
&\qquad + \sum_{m\in\mathbb{M}_N}\sum_{s\in\mathbb{S}} \mu_{m,s}\left(\sum_{n\in\mathbb{N}} \rho_{m,s}^{[n]} r_{m,s}^{[n]} - r_{\min}\right) \\
&\qquad + \sum_{m\in\mathbb{M}_N}\sum_{n\in\mathbb{N}} \nu_m^{[n]}\left(1-\sum_{s\in\mathbb{S}}\rho_{m,s}^{[n]}\right) \\
&\qquad + \sum_{m\in\mathbb{M}_N} \lambda_m\left(p_{\max}-\sum_{n\in\mathbb{N}} p_m^{[n]}\right).
\end{aligned} \tag{4}$$

Here, $\vec{\mu}$, $\vec{\nu}$, and $\vec{\lambda}$ are the set of nonnegative Lagrangian multipliers. We can find $\rho_{m,s}^{[n]}$ by taking the derivative of (4) with respect to $\rho_{m,s}^{[n]}$:

$$\frac{\partial \mathscr{L}}{\partial \rho_{m,s}^{[n]}} = \left(1 + \mu_{m,s}\right) r_{m,s}^{[n]} - \nu_m^{[n]}. \tag{5}$$

Here, $\partial\mathscr{L}/\partial\rho_{m,s}^{[n]}$ is the marginal benefit, which indicates how much $\mathscr{L}$ can be increased if IBS m assigns subchannel n to node s. Therefore, it is the best way to assign subchannel n to the node which has the largest marginal benefit. Scheduling strategy can be represented by

$$\rho_{m,s}^{[n]} = \begin{cases} 1 & \text{for } \dot{s}_m^{[n]} = \arg\max\limits_{s\in\mathbb{S}} \dfrac{\partial\mathscr{L}}{\partial\rho_{m,s}^{[n]}} \\ 0 & \text{otherwise.} \end{cases} \tag{6}$$

We can denote $\dot{s}_m^{[n]} = \rho_{m,s}^{[n]} \cdot s$ as the node scheduled by IBS m for subchannel n and $\overrightarrow{\dot{s}}$ as the set of $\dot{s}_m^{[n]}$ for $\forall m, n$. Scheduling strategy has the following interpretations. In (5), $\partial\mathscr{L}/\partial\rho_{m,s}^{[n]}$ is proportional to $r_{m,s}^{[n]}$ and $\mu_{m,s}$. This means that subchannel is assigned to the node which can achieve large $r_{m,s}^{[n]}$ preferentially. In addition, $\mu_{m,s}$ is increased if the data rate of node s is less than $r_{\min}$ since $\mu_{m,s}$ can be updated according to a gradient algorithm. Thus, the node whose data rate is less than $r_{\min}$ can be scheduled by IBSs with high probability for ensuring $r_{\min}$. In short, IBSs consider data rate and rate requirement simultaneously for scheduling.

In the case of F-nodes, such that $\dot{s}_m^{[n]} \in \mathbb{S}_{\mathbb{M}_F}$, multiple normal IBSs can assign subchannel n to the same F-node at the same time. In this case, the F-node should choose the best G-IBS m^* that sends the strongest signal for subchannel n, according to

$$m^* = \arg\max_{m\in\mathbb{M}_N} r_{m,\dot{s}_m^{[n]}}^{[n]} \quad \text{for } \dot{s}_m^{[n]} \in \mathbb{S}_{\mathbb{M}_F}. \tag{7}$$

Next, each IBS performs power allocation for the scheduled nodes $\overrightarrow{\dot{s}}$. By taking the derivative of (4) with respect to $p_m^{[n]}$, we can obtain $p_m^{[n]}$ from the Karush-Kuhn-Tucker (KKT) conditions

$$p_m^{[n]} = \left\{ \frac{1 + \mu_{m,\dot{s}_m^{[n]}}^{[n]}}{\lambda_m \ln 2 + t_m^{[n]}} - \frac{\sigma^2 + I_{m,\dot{s}_m^{[n]}}^{[n]}}{\left|h_{m,\dot{s}_m^{[n]}}^{[n]}\right|^2} \right\}^+. \tag{8}$$

Here, $x^+ = \max(0, x)$ and a taxation term $t_m^{[n]}$ is defined as

$$t_m^{[n]} = \sum_{j\in\mathbb{M}_N, j\neq m} \frac{\left|h_{m,\dot{s}_j^{[n]}}^{[n]}\right|^2 \gamma_{j,\dot{s}_j^{[n]}}^{[n]}}{\sigma^2 + \sum_{l\in\mathbb{M}_N} p_l^{[n]} \left|h_{l,\dot{s}_j^{[n]}}^{[n]}\right|^2}. \tag{9}$$

Also, let $\vec{t}$ be the set of $t_m^{[n]}$ for $\forall m, n$.

In (8), IBS m regards interference from other IBSs as noise; thus it can easily measure an inverse SINR value $(\sigma^2 + I_{m,\dot{s}_m^{[n]}}^{[n]})/|h_{m,\dot{s}_m^{[n]}}^{[n]}|^2$. Based on this value, IBS m allocates more power to the subchannel that has a good SINR value. In addition, $\mu_{m,\dot{s}_m^{[n]}}$ is related to the guarantee of $r_{\min}$ for node $\dot{s}_m^{[n]}$. If the rate of node $\dot{s}_m^{[n]}$ is lower than $r_{\min}$, IBS m allocates more power to subchannel n by increasing $\mu_{m,\dot{s}_m^{[n]}}$ according to a gradient algorithm, in order to increase the rate of node $\dot{s}_m^{[n]}$ for ensuring rate requirement. In addition, the taxation term $t_m^{[n]}$ can be interpreted as the sum of the interference that IBS m causes to nodes covered by the other IBSs for subchannel n [14]. In view of maximizing sum rates, each IBS reduces the amount of power on subchannel by increasing $t_m^{[n]}$ to reduce the interference that it causes for the other IBSs. As a result, system throughput can be assured to large value.

Based on the obtained $\vec{\rho}$ and $\vec{p}$, Lagrangian multipliers can be updated by a bisection algorithm or a gradient algorithm. In the case of using the gradient algorithm, $\vec{\mu}$ and $\vec{\lambda}$ can be updated as

$$\begin{aligned} \mu_{m,s}(i) &= \left[\mu_{m,s}(i-1) - \alpha_1\left(\sum_{n\in\mathbb{N}} \rho_{m,s}^{[n]} r_{m,s}^{[n]} - r_{\min}\right)\right]^+, \\ &\qquad \text{for } s \in \overrightarrow{\dot{s}},\ m \in \mathbb{M}_N, \\ \lambda_m(i) &= \left[\lambda_m(i-1) - \alpha_2\left(p_{\max} - \sum_{n\in\mathbb{N}} p_m^{[n]}\right)\right]^+, \\ &\qquad \text{for } m \in \mathbb{M}_N. \end{aligned} \tag{10}$$

Here, α_1 and α_2 are step sizes that are sufficiently small to guarantee the convergence. $\mu_{m,s}$ and λ_m are adjusted to guarantee constraints C1 and C4. However, $\vec{\nu}$ corresponding to constraint C2 does not need to be updated since the relaxed real value $\rho_{m,s}^{[n]}$ returns to integer value in (6). The overall procedures of the R^{2}S algorithm are described in Algorithm 1.

4. Simulation Results and Discussions

For the simulations, we assumed that there are four indoor cells, each of which had a radius of 10 m. We set $M_N = 3$, $M_F = 1$, $N = 32$, $f = 2.3$ GHz, and $r_{\min} = 0.2$ bits/s/Hz. We also defined φ as the ratio of node density between a normal and a faulty indoor cell in order to evaluate the performances in various environments. When $\varphi = 1$, nodes were equally distributed in all indoor cells. When $\varphi = 2$, twice as many nodes were generated in a faulty indoor cell asymmetrically. The bandwidth was 10 MHz and the thermal noise density was −174 dBm/Hz. The transmission powers of an IBS and an MBS were 15 dBm and 43 dBm, respectively. For the wireless channel, we utilized frequency selective Rayleigh fading generated by a Jakes fading model, and each subchannel experienced a frequency flat fading. The pathloss model for a macrocell was a modified Okumura-Hata model [15] and the pathloss model for an indoor cell was a modified COST-231 multiwall model [16]. The average cell capacity and the outage probability, $P_{\text{out}} = \Pr[R_{m,s} < r_{\min}]$, were used as performance metrics.

(1) Initialize $\vec{p} = p_{\max}/N$ and $i = 0$
(2) **repeat**
(3) $\quad i = i + 1$
(4) $\quad$ Find $\vec{\rho}$ according to (6),

$$\rho_{m,s}^{[n]} = \begin{cases} 1 & \text{for } \dot{s}_m^{[n]} = \arg\max_{s\in\mathbb{S}} \dfrac{\partial \mathscr{L}}{\partial \rho_{m,s}^{[n]}} \\ 0 & \text{otherwise} \end{cases}$$

(5) $\quad$ **if** $\dot{s}_m^{[n]} \in \mathbb{S}_{\mathbb{M}_F}$
(6) $\quad\quad$ Select the generous-IBS (G-IBS) according to (7), $m^* = \arg\max_{m\in\mathbb{M}_N} r_{m,\dot{s}_m^{[n]}}^{[n]}$ for $\dot{s}_m^{[n]} \in \mathbb{S}_{\mathbb{M}_F}$
(7) $\quad$ **end if**
(8) $\quad$ Calculate $\vec{p}$ according to (8) and (9)
(9) $\quad$ Update Lagrangian multipliers, $\vec{\mu}$ and $\vec{\lambda}$
(10) **until** $\vec{\rho}$ and $\vec{p}$ converge or $i = I_{\max}$

Algorithm 1: Radio resource sharing (R^2S) algorithm.

We compared the performance of the following algorithms:

(i) R^2S is proposed algorithm.

(ii) R^2-NS (nonsharing): normal IBSs do not take any actions for serving F-nodes, but they use the proposed scheduling and power allocation to support their own nodes.

(iii) EPA: normal IBSs serve their own nodes and F-nodes by using the proposed scheduling and equal power allocations. This is the modified version of the EPA-OIS algorithm [10] to consider constraint C1 about the requirement ensuring for the minimum data rate.

(iv) EPA-NS: normal IBSs do not take any actions for serving F-nodes, but they use the proposed scheduling and equal power allocations to support their own nodes.

The R^2S and EPA algorithms utilize the same scheduling but different power allocation. Thus, we demonstrated the performance gain achieved by power allocation by comparing the R^2S algorithm with the EPA algorithm in this paper. Figures 2 and 3 show the average cell capacity C and outage probability P_{out} versus the total number of nodes S, respectively. In all algorithms, as S increases, C increases due to multiuser diversity. This multiuser diversity can be achieved by using opportunistic user scheduling and power allocation in consideration of instantaneous channel state information of nodes in multinode systems. At the same time, the rate achieved by each node decreases as subchannels are shared by multiple nodes; in consequence, P_{out} increases. Normal IBSs try to guarantee the minimum data rate (r_{req}) for the nodes who have bad channel gains while allocating the remaining resources intensively to the nodes who have good channel gains in the R^2S algorithm. As a result, system throughput can be improved and more nodes can be served with data rates larger than r_{req} in the R^2S algorithm, compared with the EPA algorithm. In particular, in symmetric node distribution where $\varphi = 1$, the use of the R^2S algorithm improves C by 20% and reduces P_{out} by 0.1 compared to the EPA algorithm. The

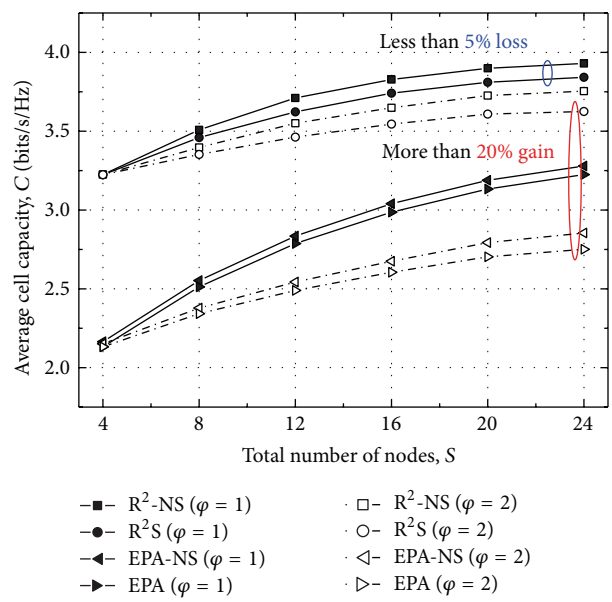

Figure 2: Average cell capacity versus total number of nodes.

power control gain of the R^2S algorithm is more effective in asymmetric node distribution where $\varphi = 2$; as a result, the performance gains of the R^2S algorithm greatly increase in both C and P_{out}. In addition, the R^2S algorithm and the EPA algorithm show good performances on network reliability by serving nodes in faulty cells, even though those algorithms achieve relatively smaller C than the R^2-NS algorithm and the EPA-NS algorithm, respectively. The R^2S algorithm especially improves P_{out} by 0.3 with degradation of C less than 5%, compared with the R^2-NS algorithm.

Figures 4 and 5 show the average cell capacity C and outage probability P_{out} versus distance between an IBS and nodes d when $S = 24$, respectively. In all algorithms, as d increases, C decreases since nodes experience serious interference from neighbor cells. In addition, channel quality between the IBS and nodes is degraded because of high

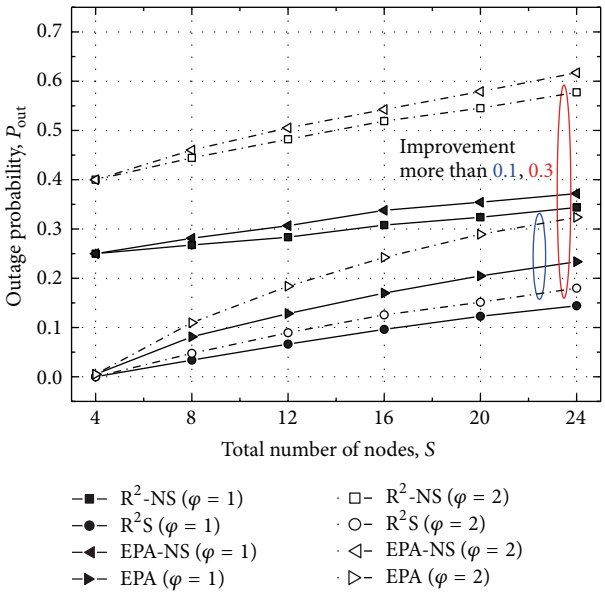

Figure 3: Outage probability versus total number of nodes.

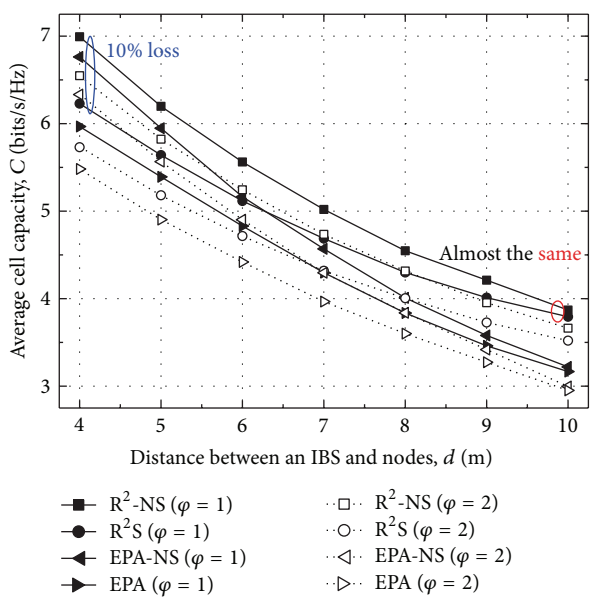

Figure 4: Average cell capacity versus distance between an IBS and nodes when $S = 24$.

path loss; as a result, P_{out} increases. This tendency becomes more severe in asymmetric node distribution. Unlike other algorithms, normal IBSs consider the constraint of the required data rate as well as the interference terms when they perform the scheduling and power allocations in the R^2S algorithm. Therefore, the R^2S algorithm obtains higher gain from its resource allocation as nodes are located in the edge of cells. In consequence, the R^2S algorithm achieves good performances on both C and P_{out} as d increases. Particularly,

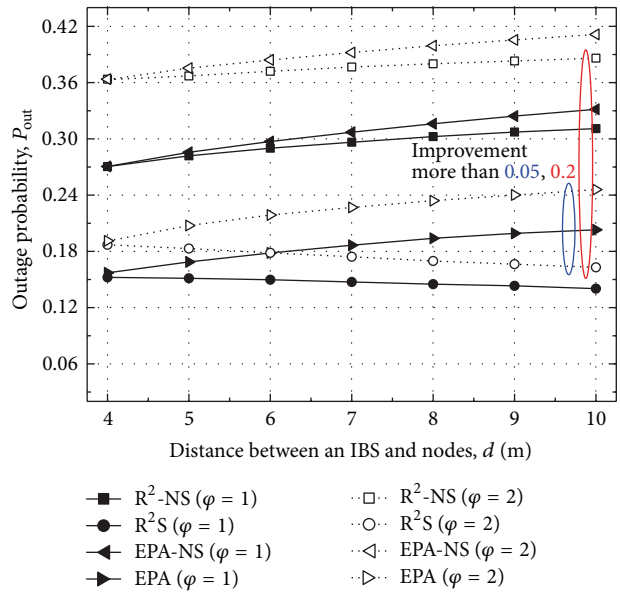

Figure 5: Outage probability versus distance between an IBS and nodes when $S = 24$.

the R^2S algorithm achieves C almost the same as that of the R^2-NS algorithm in the edge of cells. On the other hand, the difference of P_{out} between the R^2S algorithm and the R^2-NS algorithm becomes larger when d increases.

5. Conclusions

In this paper, we focused on network reliability as a means of managing a sudden network failure in OFDMA-based indoor IoT systems. To achieve reliable support for nodes in faulty as well as normal indoor cells, we proposed an R^2S algorithm using a joint optimization problem. In the R^2S algorithm, each IBS allocates subchannels and power to nodes by considering rate maximization and the minimum rate requirement for all nodes at the same time. As a result, system throughput can be maximized with guaranteeing the required node rate. In simulation results, we could show that the R^2S algorithm can resolve network failure effectively from the improvements of average cell capacity and outage probability.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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