A Minimum Energy Consuming Mobile Device Relay Scheme for Reliable QoS Support

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Abstract

Relay technology is becoming more important for mobile communications and wireless internet of things (IoT) networking because of the extended access network coverage range and reliable quality of service (QoS) it can provide at low power consumption levels. Existing mobile multihop relay (MMR) technology uses fixed-point stationary relay stations (RSs) and a divided time-frame (or frequency-band) to support the relay operation. This approach has limitations when a local fixed-point stationary RS does not exist. In addition, since the time-frame (or frequency-band) channel resources are pre-divided for the relay operation, there is no way to achieve high channel utilization using intelligent opportunistic techniques. In this paper, a different approach is considered, where the use of mobile/IoT devices as RSs is considered. In applications that use mobile/IoT devices as relay systems, due to the very limited battery energy of a mobile/IoT device and unequal channel conditions to and from the RS, both minimum energy consumption and QoS support must be considered simultaneously in the selection and configuration of RSs. Therefore, in this paper, a mobile RS is selected and configured with the objective of minimizing power consumption while satisfying end-to-end data rate and bit error rate (BER) requirements. For the RS, both downlink (DL) to the destination system (DS) (i.e., IoT device or user equipment (UE)) and uplink (UL) to the base station (BS) need to be adaptively configured (using adaptive modulation and power control) to minimize power consumption while satisfying the end-to-end QoS constraints. This paper proposes a minimum transmission power consuming RS selection and configuration (MPRSC) scheme, where the RS uses cognitive radio (CR) sub-channels when communicating with the DS, and therefore the scheme is named MPRSC-CR. The proposed MPRSC-CR scheme is activated when a DS moves out of the BS's QoS supportive coverage range. In this case, data transmissions between the RS and BS use the assigned primary channel that the DS had been using, and data transmissions between the RS and DS use CR

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sub-channels. The simulation results demonstrate that the proposed MPRSC-CR scheme extends the coverage range of the BS and minimizes the power consumption of the RS through optimal selection and configuration of a RS.

Keywords: relay, IoT, cognitive radio, QoS, end-to-end data rate, end-to-end BER, minimum power

1. Introduction

Most real-time (RT) applications have strict quality of service (QoS) requirements that require the support of several energy and frequency channel resources. Recently, as more and more RT applications are serviced on mobile phones (e.g., smartphones) and internet of things (IoT) devices, the need has arisen to expand the options for achieving high QoS support using relay technology.

Existing mobile multihop relay (MMR) technology uses fixed-point stationary relay stations (RSs) and time/frequency division duplex (TDD/FDD) with relay allocated (time/frequency) divisions to support the relay operation. This approach has limitations when a local fixed-point stationary RS does not exist. In addition, since the time-frame (or frequency-band) channel resources are separately allocated to support the relay service, there is no way to achieve higher levels of channel utilization using intelligent opportunistic techniques (e.g., cognitive radio (CR) transmission).

When a mobile station (MS) or IoT device is used as a relay station (RS), there are other issues that need to be considered. Most importantly, the energy consumed by the relaying operation must be minimized to preserve the battery power as much as possible. Since power is a scarce resource for radio transmission on mobile devices, the development of a strategy that can efficiently allocate power between the source and RSs has attracted a considerable amount of attention in recent years.

In [1], [2], and [3], low power schemes were proposed for mobile communications using a relay. In [1], a power-efficient routing (PER) mechanism was used to reduce the power consumption of user equipment during route discovery. In [2], a minimum cost (MIC) criteria based on energy pricing was used for relay selection and power allocation in cooperative wireless networks. In [3], the minimum allocation of power under a specific outage probability was derived. However, if constraints, such as end-to-end data rate, bit error rate (BER), and maximum transmission power of a downlink (DL) and uplink (UL) are asymmetric (e.g., HSDPA), the optimal configuration of the DL and UL that can satisfy the end-to-end QoS requirements need to be reconsidered in the setup algorithm simultaneously. Therefore, this paper presents a minimum transmission power consuming mobile RS selection and configuration (MPRSC) scheme, which is designed to satisfy the end-to-end data rate and BER constraints that are commonly required by RT applications. In order to enhance the spectral efficiency, CR technology is used by the RS (MPRSC-CR) proposed in this paper.

In addition, previous studies of CR-based relay technology have been reported in the following papers. In [8], CR and cooperative relay technologies were used to enhance the spectrum utilization and spatial diversity, which resulted in an increased throughput gain. In multi-hop CR networks, proper RS selection is an important issue. In related work, the authors of [9] introduced an idealized two-dimensional geometric CR network using relays in Rayleigh fading channels and showed that multi-hop relaying through shorter distances using less power can result in higher efficiency. In [10], an adaptive cooperative diversity scheme for RS selection was proposed to improve the outage probability of CR transmissions to ensure the required outage probability of primary transmissions. In [11], a joint power and channel allocation scheme based on energy pricing was shown to extend the lifetime of a cooperative network by controlling the variant transmission power and spectrum availability.

The proposed MPRSC-CR scheme presented in this paper focuses on minimizing the transmission power of the RS while satisfying the end-to-end data rate and BER constraints. Not only the transmission power and data rate but also the packet length of the BS, RS, and DS are simultaneously optimized to minimize the transmission power of the RS. To support the target end-to-end data rate, the packet length is controlled based on the number of packets/s to be transmitted and the channel conditions, where the end-to-end BER is formulated as a function of the data rate and transmission power of each node. The proposed MPRSC-CR scheme of this paper is unique in its approach based on the method that is applied, in which a RS is selected among many mobile devices in the network, where the UL and DL configuration of the selected RS is controlled to minimize the transmission power of the RS and satisfy the end-to-end data rate and BER requirements for RT applications.

The rest of this paper is organized as follows. The mobile communication system structure is presented in section 2. The MPRSC-CR scheme is introduced in section 3 and the simulation results of the proposed scheme is analyzed in section 4. Finally, the conclusion is provided in section 5.

2. Mobile/IoT Access Network Communication System Structure

When a destination station (DS) has poor connectivity with its base station (BS), the BS may need to select a MS among RS candidates to relay its signal to the DS. In this study, we focus on minimizing the transmission power of the DL and UL of selected mobile RSs to support RT data traffic in the case of a two-hop relay mobile network with adaptive modulation and adaptive power control.

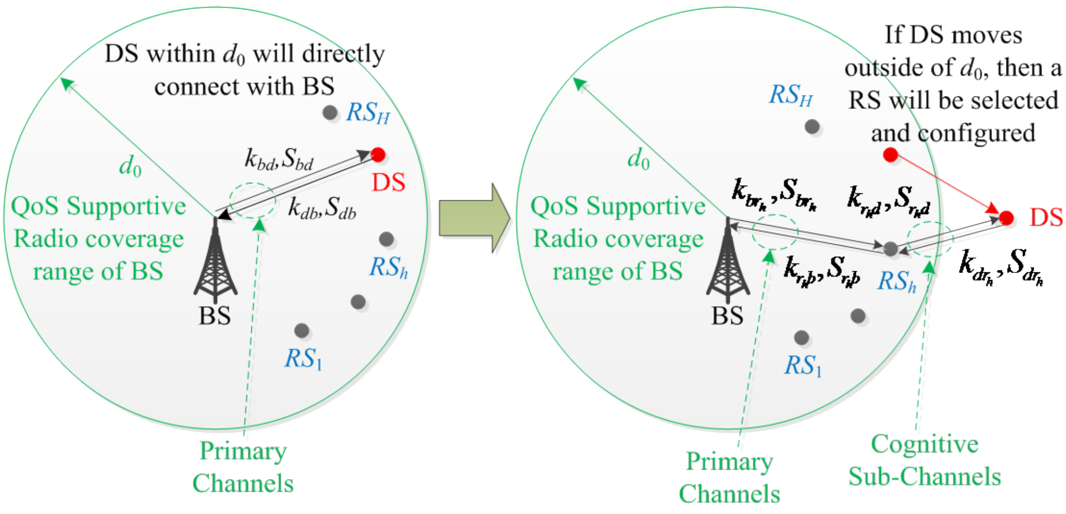

Fig. 1. Example of multiple mobile/IoT RSs and DL and UL selection in the access network.

Fig. 1 shows the operation of a MMR network model. Assume that DL and UL channels are ergodic and stationary and that there are *H* RS candidates, in the cellular service area. When the DS moves out of the required QoS supportive coverage range, the BS can transmit data to the DS through a selected relay RS_h, where RS_h will take over the DS's assigned primary channel to communicate with the BS (instead of the DS) and RS_h will use CR sub-channels to communicate with the DS. RS_h uses the configuration parameters of transmission power $S_{r_hd}(\gamma_{br_h}, \gamma_{r_hd})$ and data rate k_{r_hd} $(\gamma_{br_h}, \gamma_{r_hd})$ (in units of bits/symbol) when it transmits signals to the DS, and it uses the configuration parameters $S_{r_hb}(\gamma_{dr_h}, \gamma_{r_hb})$ and $k_{r_hb}(\gamma_{dr_h}, \gamma_{r_hb})$ when it transmit signals to the BS, in which γ_{ab} is the normalized signal-to-noise-ratio (SNR) with average $\bar{\gamma}_{ab}$ at S_{ab} = 1W, where S_{ab} is the transmission power of node *a* intended for reception at node *b*. The parameters for RS_h are configured based on the minimum transmission power of RS_h while satisfying the end-to-end data rate and BER. The transmission power and data rate, $S_{br_h}(\gamma_{br_h}, \gamma_{r_hd})$, $S_{dr_h}(\gamma_{dr_h}, \gamma_{r_hb})$, $k_{br_h}(\gamma_{br_h}, \gamma_{r_hd})$, and $k_{dr_h}(\gamma_{dr_h}, \gamma_{r_hb})$ are configured together to satisfy the end-to-end data rate and BER constraints of the DL and UL. For convenience, the configuration parameters are represented in a simplified notation using S_{br_h}, S_{r_hd}, S_{dr_h}, S_{r_hb}, k_{br_h}, k_{r_hd}, k_{dr_h}, and k_{r_hb}, respectively.

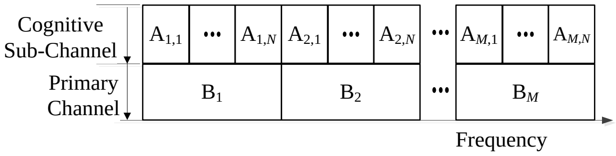

Fig. 2. Frequency allocation for PCs and CCs.

Fig. 2 shows the allocation of frequency resources for the primary channels (PCs) and cognitive sub-channels (CCs). The spectrum consists of *M* primary frequency channels, where each primary channel is divided into *N* cognitive sub-channels. Each CC can access a cognitive sub-channel when a PC does not access the same frequency band [13].

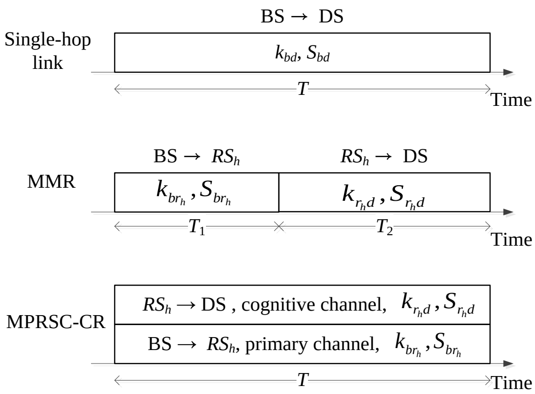

Fig. 3. Frame structures for no relay (i.e., 1-hop), MMR, and MPRSC-CR transmission.

Table 1. Notations

Parameter	Description
BS	Base station
DS	Destination station
$RS_1, \ldots, RS_H$	Relay stations candidates in the network
γ_{ab}	Normalized SNR when data is transmitted from *a* to *b*
k_{ab}	Data rate when data is transmitted from *a* to *b*
k_d	End-to-end data rate of downlink
k_u	End-to-end data rate of uplink
K_d	Minimum end-to-end data rate of downlink
K_u	Minimum end-to-end data rate of uplink
S_{ab}	Transmission power when data is transmitted from *a* to *b*
S_{b_max}	Maximum transmission power of BS
S_{m_max}	Maximum transmission power of mobile station (RS_h and DS)
BER_{ab}	Bit error rate when data is transmitted from *a* to *b*
BER_d	End-to-end bit error rate of downlink
BER_u	End-to-end bit error rate of uplink
B_d	Maximum end-to-end bit error rate of downlink
B_u	Maximum end-to-end bit error rate of uplink

We propose a CR scheme for data transmission between RS and DS. CR sub-channels are assigned based on primary channel availability. For example, if the B_1 channel is used for communication between the BS and RS, and the frequency band of B_2 channel is not used by any user, then cognitive sub-channel $A_{2,1}$ can be used for communication between the RS and DS. **Fig. 3** shows the frame structure in the cases of DL of a no relay (i.e., 1-hop) transmission, MMR, and MPRSC-CR transmissions. The UL frame structures are same as the DL frame structures.

The conditions of the proposed network are as follows:

1. Resource allocation control is conducted at the BS in a centralized manner or by a DS in a distributed manner. The data rate, transmission power, and packet slot allocation of a BS, DS, and RS are configured adaptively.
2. Mobile devices in the cellular area can be asked to serve as a RS in order to help other DSs communicate. In such cases, the MS is configured to consume minimum power in supporting the QoS of the BS to DS requirements.
3. Transmissions are executed on a frame by frame basis.
4. There are several sub-channels that PCs and CCs can be assigned to per TDD/FDD frame [13].
5. If two RSs interfere with each other, they cannot transmit over the same CR sub-channel at the same time. A RS can only transmit on a vacant sub-channel to avoid interfering with PCs and CCs.
6. CR sub-channel vacancy is determined based on the use of CC usage in the vicinity (interference range) of the selected RS and PC assignments.

3. Multihop Relay System Design

3.1 Minimum Energy Consuming Adaptive Modulation Control

In the case of the MMR, fixed modulation (MMR-FM) or adaptive modulation (MMR-AM) can be used. In the MPRCS-CR system, adaptive modulation is used, where adaptive modulation control is based on the following model. A BS transmits data to a selected RS_h during time T_1, and in the case of DL, RS_h transmits data to the DS during time T_2. Hence the transmitted amount of data in each time slot should be identical for the links between the BS and RS_h and the link between RS_h and the DS. Therefore,

$$T_1 k_{br_h} = T_2 k_{r_h d} = T k_d \tag{1}$$

since $T_1 = T\dfrac{k_d}{k_{br_h}}$, $T_2 = T\dfrac{k_d}{k_{r_h d}}$, and $T = T_1 + T_2$. Then the end-to-end data rate of the DL frame, k_d [4] can be represented as in (2).

$$k_d = (k_{br_h}^{-1} + k_{r_h d}^{-1})^{-1} \tag{2}$$

The end-to-end data rate of the UL frame, k_u, can be represented as in (3).

$$k_u = (k_{dr_h}^{-1} + k_{r_h b}^{-1})^{-1} \tag{3}$$

For a signal transmitted from node *a* to node *b*, the received SNR at *b* can be expressed as $\dfrac{S_{ab}\gamma_{ab}}{d_{ab}^{\alpha}}$, where d_{ab} is the distance between node *a* and node *b*, and α is the channel loss exponent [5][7]. The BER of the channel between *a* and *b* can be approximated as

$$BER_{ab} = c_1 \exp\left(\frac{-c_2 S_{ab}\gamma_{ab}}{(2^{c_3 k_{ab}} - c_4) d_{ab}^{\alpha}} \right) \tag{4}$$

where $c_1 \sim c_4$ are the BER parameters for *M*-QAM modulation (c_1 = 0.2, c_2 = 1.6, c_3 = 1.0, and c_4 = 1.0) [5]. The end-to-end BER of the DL frame, BER_d, can be obtained from (5).

$$BER_d = 1 - (1 - BER_{br_h})(1 - BER_{r_h d}) \approx BER_{br_h} + BER_{r_h d} \tag{5}$$

In a similar fashion, the approximated end-to-end BER of the UL frame, BER_u, can be obtained from (6).

$$BER_u \approx BER_{dr_h} + BER_{r_h b} \tag{6}$$

The average transmission power of RS_h, $\bar{S}_{r_h}$, can be obtained from (7).

$$\bar{S}_{r_h} = \int_0^\infty\int_0^\infty \frac{S_{r_h d} k_d}{k_{r_h d}} p(\gamma_{br_h}) p(\gamma_{r_h d}) d\gamma_{br_h} d\gamma_{r_h d} + \int_0^\infty\int_0^\infty \frac{S_{r_h b} k_u}{k_{r_h b}} p(\gamma_{dr_h}) p(\gamma_{r_h b}) d\gamma_{dr_h} d\gamma_{r_h b} \quad (7)$$

Because the optimal solutions of DL and UL are independent of each other, the optimization problems for DL and UL are respectively separated as (8) and (9),

Minimize $\bar{S}_{r_h d} = \int_0^\infty\int_0^\infty \frac{S_{r_h d} k_d}{k_{r_h d}} p(\gamma_{br_h}) p(\gamma_{r_h d}) d\gamma_{br_h} d\gamma_{r_h d}$ (8)

Subject to $BER_d \le B_d$

$k_d \ge K_d$

$S_{br_h} \le S_{b\_\max}$

$S_{r_h d} \le S_{m\_\max}$

and

Minimize $\bar{S}_{r_h b} = \int_0^\infty\int_0^\infty \frac{S_{r_h b} k_u}{k_{r_h b}} p(\gamma_{dr_h}) p(\gamma_{r_h b}) d\gamma_{dr_h} d\gamma_{r_h b}$ (9)

Subject to $BER_u \le B_u$

$k_u \ge K_u$

$S_{r_h b} \le S_{m\_\max}$

$S_{dr_h} \le S_{m\_\max}$

where the lower-bound limits of the DL and UL data rates are K_d and K_u, respectively, and the upper-bound limits of the DL and UL BER are B_d and B_u, respectively; $S_{b\_\max}$ is the maximum transmission power of the BS, and $S_{m\_\max}$ is the maximum transmission power of the MSs.

The Lagrange equation that provides the optimal solution of (8), L_d, is provided in (10).

$$L_d = \bar{S}_{r_h d} + \lambda_1 (BER_d - B_d) + \lambda_2 (k_d - K_d) + \lambda_3 (S_{br_h} - S_{b\_\max}) + \lambda_4 (S_{r_h d} - S_{m\_\max}) \quad (10)$$

The dual problem of the minimization problem of (8) is presented in (11).

$$D_d(\lambda_1, \lambda_2, \lambda_3, \lambda_4) = \inf_{S_{br_h}, S_{r_h d}, k_{br_h}, k_{r_h d}} L_d \quad (11)$$

We can solve the dual problem by deriving the solution for $\frac{\partial L_d}{\partial S_{br_h}}$ =0, $\frac{\partial L_d}{\partial S_{r_h d}}$ =0, $\frac{\partial L_d}{\partial k_{br_h}}$ =0, and $\frac{\partial L_d}{\partial k_{r_h d}}$ =0. However, if the number of selectable options of transmission power and data rate are respectively denoted as *S* and *k*, $S^2 k^2$ iterations times the number of calculations are required to solve the optimization problem.

For the case of DL, when $S_{br_h} = S_{b\_\max}$, $k_d = K_d$, and $BER_d = B_d$, $\overline{S}_{r_h d}$ is at minimum. Then the optimization problems can then be solved much more quickly and easily, and only *k* iterations times the number of calculations is required, resulting in a significantly more scalable algorithm to obtain the solution. For the optimal solution of $\overline{S}_{r_h d}$, based on (2), (4), and (5), the optimized solution for $S_{r_h d}$ and k_{br_h} is provided in (12), which is the optimal solution for the proposed MPRSC-CR scheme.

$$S_{r_h d} = \frac{(2^{c_3 k_{r_h d}} - c_4) d_{r_h d}^{\alpha}}{-c_2 \gamma_{r_h d}} \times \ln\left(\frac{B_d}{c_1} - \exp\left(\frac{-c_2 S_{b\_\max} \gamma_{br_h}}{d_{br_h}^{\alpha}(2^{c_3 k_{br_h}} - c_4)}\right)\right) \tag{12}$$

$$k_{br_h} = (K_d^{-1} - k_{r_h d}^{-1})^{-1} \tag{13}$$

If k_{br_h} and $k_{r_h d}$ are integers, the optimal solution for $\overline{S}_{r_h d}^{*}$ can be obtained using the following steps.

Step 1. Initialize $S_{br_h} = S_{b\_\max}$.

Step 2. From $k_{r_h d} = \lfloor k_d \rfloor + 1$ to $k_{r_h d} = \frac{1}{c_3} \log_2\left(\frac{c_2 \gamma_{br_h} S_{b\_\max}}{\ln(c_1 / B_d)} + c_4\right)$, iterate Step 2.1 through Step 2.5.

Step 2.1. Compute k_{br_h} from equation (13).

Step 2.2. Compute $S_{r_h d}$ from equation (12).

Step 2.3. Compute $\overline{S}_{r_h d}$ from equation (9).

Step 2.4. If $\overline{S}_{r_h d}$ is less than the previous $\overline{S}_{r_h d}$ value, then update k_{br_h}, $k_{r_h d}$, $S_{r_h d}$, and $\overline{S}_{r_h d}$, or else hold the previous values.

Step 2.5. Increase $k_{r_h d}$ by 1.

Step 3. The resulting $\overline{S}_{r_h d}$ obtained from Step 2 is the minimum solution $\overline{S}_{r_h d}^{*}$.

The optimal solution for $\overline{S}^{*}_{r_h b}$ can also be obtained from the proposed scheme by replacing the BS-to-RS and RS-to-DS parameters with the DS-to-RS and RS-to-BS parameters, respectively. The minimum average transmission power of RS_h, $\overline{S}^{*}_{r_h}$ is presented in (14).

$$\overline{S}^{*}_{r_h} = \overline{S}^{*}_{r_h d} + \overline{S}^{*}_{r_h b} \tag{14}$$

The minimum power consuming RS among many MSs in the network, RS_{opt}, is selected based on the follow criterion:

$$RS_{opt} = \arg_{RS_h \in \Omega} \min(\overline{S}^{*}_{r_h}) \tag{15}$$

Through the above process, the selected RS_{opt} will consume minimum power while satisfying the end-to-end BER and data rate constraints. These procedures may be executed by a BS or a DS or by a separate multihop network controller.

3.2 CR Transmission Control Model

A channel for a primary user channel (PC) will be used for communication between the BS and RS_h, and a CR sub-channel will be used for data transmission between RS_h and the DS. The controller can control k_d and k_u based on

$$k_d = \min(k_{br_h}, k_{r_h d}) \tag{16}$$

$$k_u = \min(k_{dr_h}, k_{r_h b}) \tag{17}$$

where $\overline{S}_{r_h d}$ and $\overline{S}_{r_h b}$ can be obtained from

$$\overline{S}_{r_h d} = \int_0^\infty \int_0^\infty S_{r_h d}\, p(\gamma_{br_h})\, p(\gamma_{r_h d}) d\gamma_{br_h} d\gamma_{r_h d} \tag{18}$$

$$\overline{S}_{r_h b} = \int_0^\infty \int_0^\infty S_{r_h b}\, p(\gamma_{dr_h})\, p(\gamma_{r_h b}) d\gamma_{dr_h} d\gamma_{r_h b} \tag{19}$$

The optimization statements of (8) and (9) lead to (16) and (17), in which $k_{br_h} \geq K_d$, $k_{r_h d} \geq K_d$, $k_{dr_h} \geq K_u$, and $k_{r_h b} \geq K_u$ is required. The optimal solution that minimizes $\overline{S}_{r_h d}$ and $\overline{S}_{r_h b}$ can be obtained from (20) and (21).

$$k_{br_h} = k_{r_h d} = K_d \tag{20}$$

$$k_{dr_h} = k_{r_h b} = K_u \tag{21}$$

From (11), (18), (19), (20), and (21), $\bar{S}^*_{r_h d}$ and $\bar{S}^*_{r_h b}$ can be obtained; and consequently $\bar{S}^*_{r_h}$ can be obtained from the sum of $\bar{S}^*_{r_h d}$ and $\bar{S}^*_{r_h b}$.

The average data rate of DL and UL is formulated as (22) and (23), respectively.

$$\bar{k}_d = \int_0^\infty \int_0^\infty k_d \, p(\gamma_{br_h}) p(\gamma_{r_h d}) d\gamma_{br_h} d\gamma_{r_h d} \tag{22}$$

$$\bar{k}_u = \int_0^\infty \int_0^\infty k_u \, p(\gamma_{dr_h}) p(\gamma_{r_h b}) d\gamma_{dr_h} d\gamma_{r_h b} \tag{23}$$

4. Performance Analysis

In this section, the performance of the no relay (1-hop) case, MMR-FM, MMR-AM, and the proposed MPRSC-CR scheme is analyzed. These schemes are adoptable to the 3GPP LTE standard devices because they can use QPSK, 16-QAM, and 64-QAM modulation based on adaptive power control and each time slot is divided into resource blocks [21]. Each time slot and subcarrier can be adaptively allocated depending on the proposed schemes. The proposed schemes can also be implemented on the foundation of the IEEE 802.16j protocol. IEEE 802.16j is a standard realizing MMR networks. The frame structure of 802.16j is separated into a DL sub-frame and UL sub-frame and each DL and UL sub-frame are divided to an access zone and relay zone. In the access zone, for example, the BS can transmit to the RS or MS in the DL case, and the RS can relay signals to the MS through the relay zone [22]. If CR is used, we don't need to separate the access zone and relay zone. The primary channels are used as the access zone and the CR sub-channels are used for relays.

The proposed MPRSC-CR is compared to the decode-and-forward (DF) mobile multi-hop relay (MMR) with fixed modulation (MMR-FM) scheme of [2] and [3], and also compared to the 2-hop simple relaying without concurrency MMR with adaptive modulation (MMR-AM) of [4]. The performance of the proposed MPRSC-CR is compared to MMR-FM and MMR-AM in terms of average transmission power, average coverage range (based on satisfaction of the constraints), and average data rate in Figs. 5, 6, and 7, respectively.

Fig. 4 provides a comparison of the required transmission power of RS_h when using MMR-FM, MMR-AM, and MPRSC-CR, for the conditions of S_{b_max} = 16 W, S_{m_max} = 400 mW, K_d = 2 bits/symbol, K_u = 1 bits/symbol, B_d = 0.001, and B_u = 0.001. The left graph of **Fig. 4** shows the optimal solution of the transmission power of RS_h to minimize the average transmission power of RS_h by satisfying the end-to-end BER and data rate, where $\gamma_{r_h d} = \gamma_{dr_h}$ = 30 dB and $d_{br_h} = d_{r_h d}$ =1 km. Depending on the variation in γ_{br_h}, $S_{r_h b}$ changes, where if γ_{br_h} increases, then $S_{r_h b}$ is reduced, and $S_{r_h d}$ does not change. If γ_{br_h} is very low, it is difficult to satisfy the required QoS, so data transmission is stopped. The right graph of **Fig. 4** shows the transmission power of RS_h that satisfies the required QoS, for the conditions of

$\gamma_{r_h b} = \gamma_{br_h}$ = 30 dB. Based on the fundamental relations, $S_{r_h d}$ is inversely proportional to γ_{br_h}, and $S_{r_h b}$ is not influenced by γ_{br_h}. In the case of MPRSC, $S_{r_h d}$ = 0.023 W, and $S_{r_h b}$ = 0.099 W, where γ_{br_h} = 20 dB and $\gamma_{r_h d}$ =30 dB. The optimal solution of the data rate is calculated as k_{br_h} = 6 bits/symbol, $k_{r_h d}$ = 3 bits/symbol, k_{dr_h} = 2 bits/symbol, and $k_{r_h b}$ = 2 bits/symbol.

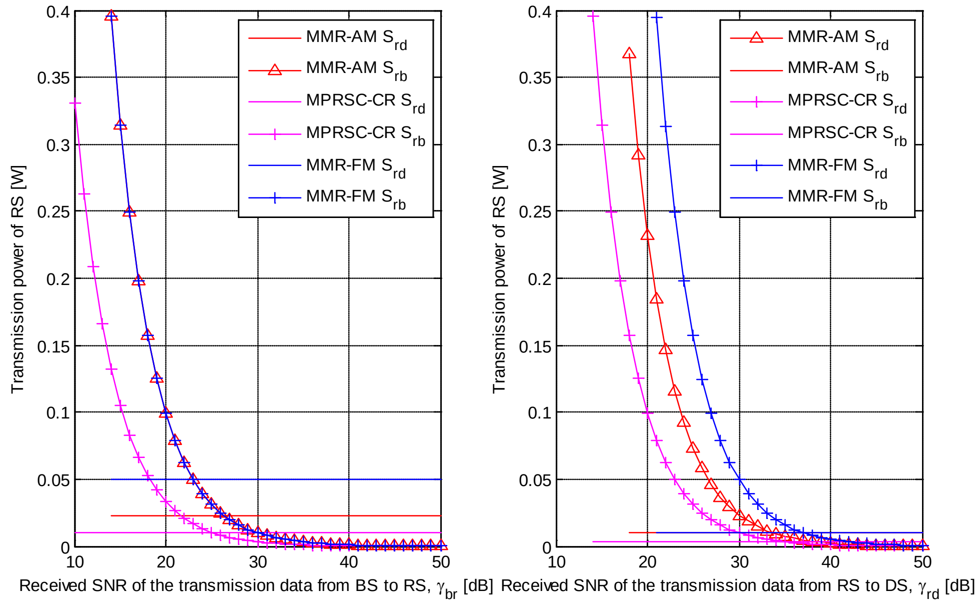

Fig. 4. Transmission power of RS, S_{br_h} and $S_{r_h d}$.

In the case of DL, $T_1 = \frac{1}{3}T$ and $T_2 = \frac{2}{3}T$. At UL, $T_1 = \frac{1}{2}T$ and $T_2 = \frac{1}{2}T$. In the case of MPRSC-SC, $S_{r_h d}$ = 0.01 W and $S_{r_h b}$ = 0.033 W, where the optimal solution of data rates are k_{br_h} = $k_{r_h d}$ = 2 bits/symbol and $k_{dr_h} = k_{r_h b}$ = 1 bits/symbol. In the case of MMR-FM, k_{br_h} and $k_{r_h d}$ are respectively set to $2\times K_d$ and 4 bits/symbols; k_{dr_h} and $k_{r_h b}$ are respectively set to $2\times K_u$ and 2 bits/symbols; T_1 and T_2 are respectively set to $T_1 = \frac{1}{2}T$ and $T_2 = \frac{1}{2}T$. To satisfy the required QoS, the DL and UL transmission power of the RS are $S_{r_h d}$ = 0.049 W and $S_{r_h b}$ = 0.033 W, respectively.

Fig. 5 provides a comparison of the optimal average transmission power of RS_h of a mobile relay network, where $\overline{S}^*_{r_h}$ is based on using MMR-FM, MMR-AM, and MPRSC-CR. The $\overline{S}^*_{r_h}$ values obtained from the experiments are 471 mW, 205 mW, and 136 mW, respectively, when $\gamma_{br_h} = \gamma_{r_h b} = 15dB$ and $\gamma_{dr_h} = \gamma_{r_h d} = 25dB$. When using the MPRSC-CR scheme, the power consumption of the RS is reduced to 44% and 29% compared to using MMR-AM and MMR-FM , respectively.

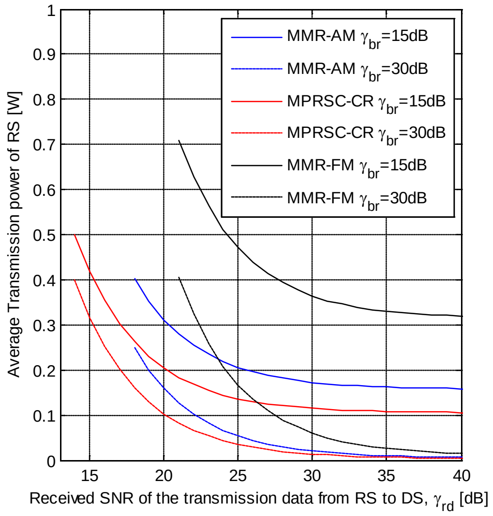

Fig. 5. Average transmission power of RS$_h$.

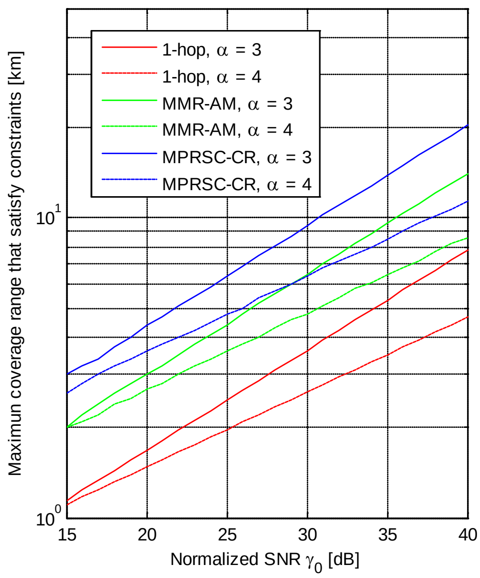

Fig. 6. Maximum coverage range performance of 1-hop, MMR-AM, and MPRSC-CR.

Fig. 6 shows comparison of the maximum coverage ranges for the 3 schemes of: no relay (i.e., 1-hop), MMR-AM, and MPRSC-CR. The maximum coverage range of the 1-hop case is obtained from the minimum distance that satisfies the QoS, where $S_{bd} = S_{b\_\max}$, $S_{db} = S_{m\_\max}$, $BER_d = BER_{bd}$, and $BER_u = BER_{db}$. To make the comparison fair with the 1-hop case, for MMR-AM and MPRSC-CR schemes, simulation was conducted using

$S_{br} = S_{b\_max}$ and $S_{rd} = S_{rb} = S_{dr} = S_{m\_max}$, where the maximum coverage range was obtained by computing the distance that satisfies (2)~(6). For the normalized SNR value of γ_0 = 30 dB, the maximum coverage range of the 1-hop case is 3.62 km, MMR-AM is 6.5 km, and MPRSC-CR is 9.4 km, where $\gamma_{br_h} = \gamma_{r_hd} = \gamma_{dr_h} = \gamma_{r_hd} = \gamma_0$, and γ_0 is the received SNR when the distance between the transmitter and the receiver is 1 km and the transmission power is 1 W. The MPRSC-CR scheme increases the coverage range of the network by more than 145% compared to the MMR-AM scheme, and increases the coverage range by 261% compared to the 1-hop scheme.

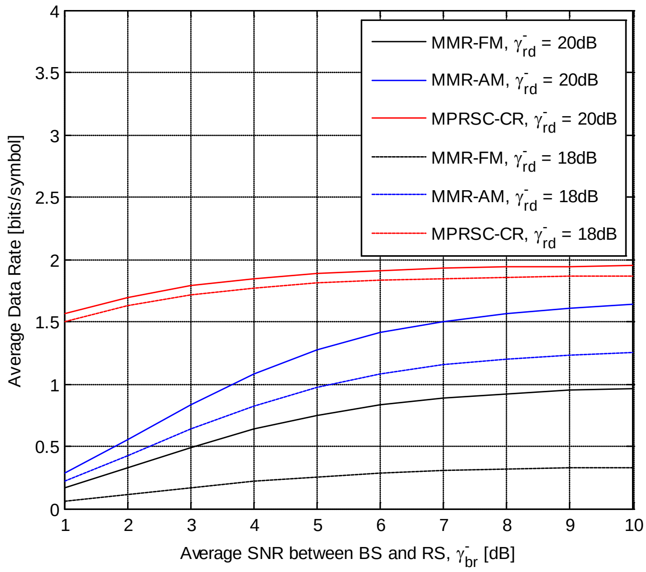

Fig. 7. Average data rate of, MMR-FM, MMR-AM, and MPRSC-CR.

Fig. 7 shows the average data rate of DL for the 3 schemes of MMR-FM, MMR-AM, and MPRSC-CR where $\bar{\gamma}_{br}$ and $\bar{\gamma}_{rd}$ are the average SNR of the Rayleigh fading channel from BS to RS and RS to DS, respectively. Since MPRSC-CR requires a lower SNR channel condition in supporting the same target data rate compared to MMR-FM and MMR-AM, the average data rate of MPRSC-CR is higher than these two schemes for the same SNR level, as presented in Fig. 7.

5. Conclusion

In this paper, a minimum transmission power consuming RS selection and configuration scheme that uses CR technology to communicate with the DS is proposed. Minimum transmission power consuming RS selection and configuration is required because the RS is selected among the mobile/IoT devices that are in the vicinity of the DS. Since battery operated mobile/IoT devices are used as RSs in the proposed MPRCS-CR scheme, power minimization becomes the most important requirement. The proposed MPRSC-CR scheme is activated when a DS moves out of the BS's QoS supportive coverage range, where communication between the RS and BS use the assigned primary channel that the DS had been using, and communication between the RS and DS use CR sub-channels. The simulation results demonstrate that the proposed MPRSC-CR scheme extends the coverage range and helps to reduce the required power consumption of the RS compared to the 1-hop (i.e., no relay case), MMR-FM, and MMR-AM relay schemes.

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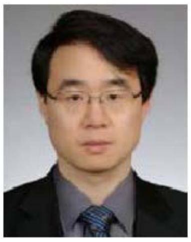

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