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Energy-Efficient Buffer Aided Routing and TAPS for Multihop Wireless Networks

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Abstract- A two-dimensional Channel Probability Space (CPS) based on the source-relay and relay-destination channel. In this paper, a non-linear CPS division method is used a single relay and the RN is competent for the moment storing the received packets. Extensively, a non-linear CPS method, which partitions the CPS into more than a few regions representing the quality of the specific channels plus an outage region. In proposed, a non-linear CPS division method with multi relay for since the relays with the best source-relay and the best relay-destination channels are selected for reception and transmission. We provide a comprehensive analysis of the outage probabilities of CPS for a decode-and-forward protocol in Rayleigh fading.

Key Words- Opportunistic routing, buffer, energy consumption, energy dissipation, channel space with relays.

I. INTRODUCTION

Minimizing the energy consumption of a relay-aided wireless communication system is still an open problem at the time of writing. Employing a relay between the Source Node (SN)[1] and the Destination Node (DN) is one of the most basic methods that can be used for minimizing the energy consumption. It is traditionally assumed that a packet is transmitted from the SN to the DN via the Relay sequentially. For the expediency of description, we refer to this as *"the non-linear channel space"* in our forthcoming discourse. This scheme results in a range of advantages over conventional single-hop communications.

The drawback in the conventional transmission is specifically the Bit Error Ratio (BER)/outage performance, which cannot benefit from the maximum achievable diversity order. This is because there is a single channel selection scheme, since the channel to be activated at a specific time instant is predefined and it is activated regardless of its instantaneous Channel Quality (CQ). In order to improve the achievable performance of relaying systems, novel signaling schemes have been proposed, which require the nodes to have a store-and wait capability. Additionally, our previous contributions proposed a buffer-aided transmission scheme, namely the Multihop Diversity (MHD)[2] transmission, philosophically which relies on temporarily storing the received packets and on activating the channel having the highest instantaneous SNR. Both our simulation results and theoretical analysis demonstrated that MHD transmissions are capable of a substantial selection diversity gain. Recently, a relay-relation scheme was proposed, while full-duplex relaying was discussed. As a further advance, adaptive link selection was proposed.

Without loss of generality, let us consider a single-relay-aided network scenario, where the SN-RN distance is lower than the RN-DN distance. Even though the SN-RN distance may be different from the RN-DN distance[3] , the probability of either of those two hops being selected should be the same, otherwise the system becomes unstable, which results in a buffer-overflow at the RN. Our buffer-aided transmission scheme relies on the channel quality at this specific point for selecting the most suitable channel for its next transmission.

The rest of this paper is organized as follows. Section II presents our system model and our assumptions, while Section Ill introduces the CPS hypothesis and proposes our new channel activation method. In Section IV, we provide our statistical and simulation results. Finally, our terminations are offered in Section V.

II. OVERVIEW OF ENERGY-EFFICIENT ROUTING PROTOCOLS

In this section, a brief overview of the routing operations performed by energy-efficient protocols EXoR, MQAM, MMRS, SFD-MMRS are discussed.

1. Cross-Layer Aided Energy-Efficient Opportunistic Routing in Ad Hoc Networks

Two accurate energy-consumption based OFs are constructed, which are used for the TR and the OR respectively[4] . We exploit the knowledge of both the Frame Error Ratio (FER) within the physical layer, and of the number of MAC retransmissions as well as of the number of relays in the network layer.

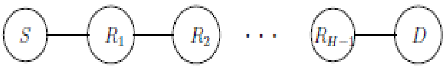

Fig 1. Test-topology having one source, one destination and $(H-1)$ relay nodes.

A. TR algorithm

The performance of the single-hop route and of an idealized network was characterized in Subsections II-A and II-B, which may be readily extended to existing routing protocols, such as the DSR (Dynamic Source Routing), AODV (Ad hoc On-demand Distance Vector) and DYMO[5] (DYnamic Manet On-demand) routing protocols. During the route discovery process, the routing packets are used for gathering the necessary information and for feeding it back to the source. Then the source makes the final decision required for sending the data packets. The most important feature of traditional routing is that the route is selected first, then the packets are always delivered along this particular route, until it is broken, for example due to node-mobility. At that moment, a sub-optimal candidate route is chosen by route-repair, or the route rediscovery process will be re-activated for finding a totally new route.

B. OR algorithm

In Section II-C, the minimum NEC[6] is obtained by finding the optimal power allocation. Although the network topology in Fig. 1 has only two hops, this algorithm may be extended to a large network, where the OR principle is employed for each hop. Meanwhile, the optimal transmit power of each node is found for the sake of minimizing the NEC required for the successful passage of a packet from that node to the destination. Therefore, Algorithm 2 is conceived for calculating the minimum NEC by carrying out optimum distance-dependent power allocation at each node, hop-by hop.

The rest of the paper is organized as follows. Section II theoretically analyzes the performance of the system for the single-hop route, for the TR and for the OR. Section III describes our energy-efficient routing algorithms conceived for TR and OR, respectively. The delay distribution of OR is also analyzed. Finally, Section IV analyzes the overall performance of the system, while Section V provides our conclusions.

2. Multihop Diversity-A Precious Source of Fading Mitigation in Multihop Wireless Networks

In wireless multi hop communications, source nodes (SNs) send information to the corresponding destination nodes (DNs) via intermediate relay nodes (RNs), which provides a range of advantages over conventional single-hop communications. Typically, these advantages may include an improved energy-efficiency and extended coverage, improved link performance, enhanced throughput, simplicity and high flexibility of network planning, etc.

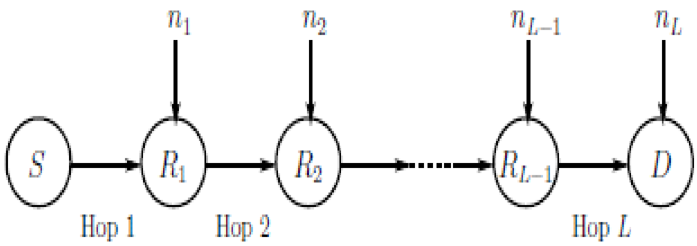

Fig. 2. System model for a multihop wireless link, where SN S sends message to DN D via $(L-1)$ intermediate RNs.

A. Lower-Bound Bit Error Rate

In order to derive the lower-bound BER[7] , we first derive the single hop BER, *PL, e*, under the assumptions that every RN has an infinite buffer and that a node always has packets prepared to send. Then, the lower-bound of the end-to-end BER, *PL,E*, of the multihop link shown in Fig. 1 is derived. The subscript '*L*' in *PL,e* and *PL,E* stands for the lower-bound.

B. Lower-Bound Outage Probability

The outage probability is the probability of the event that the maximal SNR of the *L* hops is lower than a pre-set threshold. When this event occurs, either no data is transmitted on the multihop link in order to guarantee the minimum required BER, or the BER becomes higher than a predicted value, if data is still transmitted. Given a threshold γT , the lower-bound outage probability.

In this section, we provide both the BER and outage probability of multihop links employing various MQAM schemes, in order to illustrate the effect of the RNs' buffer size on the achievable multihop diversity gain. In these figures, the lower-bounds were evaluated from the formulas derived in Section III, while the other results were obtained via simulations. For the sake of comparison, in these figures, the corresponding BER and outage performance results of the conventional multihop transmission scheme were provided.

3. Max-Max Relay Selection for Relays with Buffers

COOPERATIVE communication techniques have gained a lot of interest from both academia and industry due to their ability to mitigate fading in wireless channels by introducing spatial diversity. The relay selected according to the criterion may not simultaneously enjoy the best *S-R* and the best *R-D* channels[8] . If the relays are equipped with buffers, they can store the packets received from the source and do not have to re-transmit them immediately in the next time slot. As a result, it is possible to use the relay with the best *S-R* channel for reception and the relay with the best *R-D* channel for transmission.

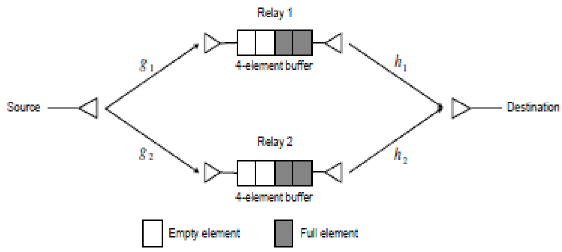

Fig. 3. Relay network with one source, one destination, and two relays where each relay is equipped with a four-element buffer.

A. Hybrid Relay Selection

If buffer over- and underflows are to be avoided, the relay selection criterion cannot only depend on the channel status as in MMRS but also has to take into account the status of the buffer. The basic idea is to use BRS if the buffer of the relay selected for reception is full or the buffer of the relay selected for transmission is empty. In all other cases, MMRS is used. We assume that all buffers have *Lb* elements and each element can store one packet.

We proposed two new relay selection schemes for relays with buffers. The first scheme, MMRS, always selects the relays with the best *S-R* and the best *R-D* channels for reception and transmission, respectively, and operates under the assumption that the buffers at the relays are neither full nor empty. However, for finite buffer sizes empty and full buffers cannot be avoided. For this reason, we proposed HRS which overcomes the limitations of MMRS by combining conventional BRS and MMRS. HRS employs MMRS if the buffer of the relay selected for reception is not full and the buffer of the relay selected for transmission is not empty, and conventional BRS otherwise. A comprehensive analysis of the outage probabilities and the SEPs of MMRS and HRS revealed that both schemes achieve the same diversity gain as BRS. HRS approaches this SNR gain as the buffer size increases. For $N = 3$ relays, HRS can achieve an SNR gain of about 2 dB compared to BRS if an average delay of 30 transmission intervals can be afforded.

4. Space Full-Duplex Max-Max Relay Selection for Relays with Buffers.

SFD-MMRS uses relay selection and half-duplex (HD)[9] relays with buffers to mimic full-duplex (FD) relaying. It allows the selection of different relays for reception and transmission, which in turn enables simultaneous reception and transmission. The basic idea of SFD-MMRS is to choose different relays for reception and transmission, according to the quality of the channels, so that the relay selected for reception and the relay selected for transmission can receive and transmit at the same time. More recently, for a network consisting of a source, a destination, and multiple relays with buffers, we have proposed in [10] a new relay selection scheme called max-max relay selection (MMRS), which selects the relays with the best S-R and the best R-D channels for reception and transmission, respectively. However, using the best channels allows improving both the outage probability and the throughput but cannot avoid the pre-log factor in the capacity expression.

In this paper, in order to overcome the HD limitation, we are aiming at mimicking FD relaying with buffered HD relays in a relay network with relay selection capability. For this purpose, we propose a new selection rule referred to as space full duplex MMRS (SFD-MMRS). The basic idea of SFD-MMRS is to choose different relays for reception and transmission, according to the quality of the channels, so that the relay selected for reception and the relay selected for transmission can receive and transmit at the same time.

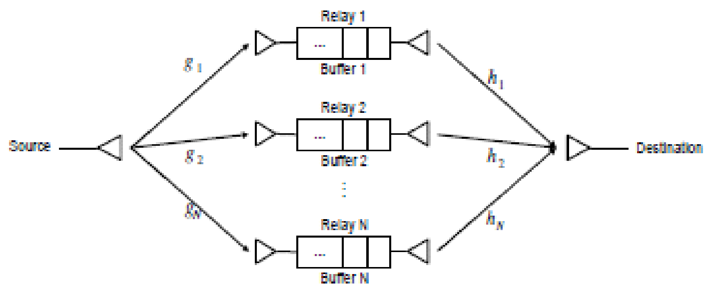

Fig. 4. Relay network with one source, one destination, and N relays where each relay is equipped with a buffer.

A. Review of Max-Max Relay Selection

MMRS has recently been proposed. The basic idea of MMRS[10] is that the relays with the best S-R and the best R-D channels are selected for reception and transmission, respectively. Fig.4 is made possible with the use of buffers at the relays. Indeed, if the relays are equipped with buffers, they can store the packets received from the source and do not have to forward them immediately in the next time slot to the destination. In MMRS, the best relay for reception during the first time slot, and the best relay for transmission during the second time slot.

B. Space Full-Duplex Max-Max Relay Selection

In the HD protocol was adopted for MMRS which reduces the capacity of the whole network. One way to improve the capacity of the network when MMRS is used is to allow Rbr1 and Rbt1 to receive and transmit simultaneously, respectively, when Rbr1 6= Rbt1. This protocol allows to circumvent the HD limitation partially, i.e., only when Rbr1 6= Rbt1. However, when Rbr1 = Rbt1, the HD protocol would still have to be utilized1. To completely bypass the HD limitation, we propose to always select different relays for reception and transmission. We refer to the new scheme as SFD-MMRS.

The principle of SFD-MMRS is that if the best S-R and the best R-D channels do not share the same relay, i.e., br1 6= bt1, we select the relay with the best S-R channel for reception and the relay with the best R-D channel for transmission, as in MMRS.

In this section, we assess the performance of the proposed SFD-MMRS scheme and compare it with that of HD BRS, HD MMRS, and the schemes proposed and. For brevity and notational convenience, in this section, we refer to the schemes, which use two relays alternately, as alternate relaying (AR) and buffered AR, respectively. As expected, we observe that as the buffer size increases, the performance of SFD-MMRS with finite buffer size converges to that of SFD-MMRS with infinite buffer size. In particular, for B ≥ 100, SFD-MMRS with finite buffer size achieves a performance very close to that of SFDMMRS with infinite buffer size. Based on this observation and for clarity reasons, we assume in the following that large enough buffer sizes are used and hence we only show results for the infinite buffer size case.

we examine the effect of the relay buffer size, B, on the average delay introduced by SFD-MMRS. We assume SNR = 30 dB. The average delay corresponds to the number of transmission interval durations (i.e., packets) that the last information bit contained in a packet transmitted by the source is stored at a relay before it arrives at the destination, i.e., a delay of one means that the packet is stored at the relay in one transmission interval and all information bits controlled in the packet are retransmitted in the next transmission interval. As projected, the average delay increases with increasing buffer size. Furthermore, the average delay increases as the number of relays increase. We also observe that buffered AR has an average delay of one packet for all buffer sizes which can be explained by the fact that for SNR = 30 dB buffered AR uses buffering very seldom. Thus, the average delays of less than 20 (30) transmission intervals are adequate for SFD-MMRS to closely approach the performance obtained with infinite buffer sizes for N = 2 (N = 3) relays.

In SFD-MMRS, we always select different relays for reception and transmission so that simultaneous reception and transmission is possible, all the time. We analyzed the capacity of SFD-MMRS for adaptive rate transmission for the case of infinite buffer size. Moreover, we proposed a practical implementation of SFD-MMRS
for the case of finite buffer size. Simulation results showed that SFD-MMRS achieves a higher capacity than until that time the capacity of SFD-MMRS exceeds twice the capacity of HD BRS.

III. EXISTING SYSTEM FOR ENERGY-EFFICIENT

Energy-Efficient Buffer-Aided Relaying Relying on Non-Linear Channel Probability Space Division

Employing a relay between the Source Node (SN) and the Destination Node (DN) is one of the most basic methods that can be used for minimizing the energy consumption. It is traditionally unspecified that a packet is transmitted from the SN to the DN via the Relay Node (RN) sequentially. The drawback in the single relay is specifically the Bit Error Ratio (BER)/outage performance, which cannot benefit from the maximum achievable diversity order. This is because there is no channel selection scheme, since the channel to be activated at a specific time instant is predefined and it is activated regardless of its instantaneous Channel Quality (CQ).

The motivation behind this paper is to fully exploit the advantages of buffer-aided transmissions. Without loss of generality, let us consider a single-relay-aided network scenario, where the SN-RN distance is lower than the RN-DN distance. Even though the SN-RN distance may be different from the RN-DN distance, the probability of either of those two hops being selected should be the same, otherwise the system becomes unstable, which results in a buffer-overflow at the RN.

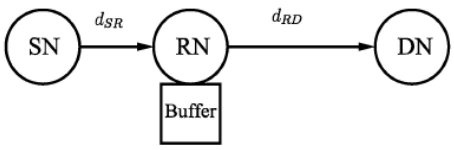

Fig. 5. System model for a buffer-aided three-node network, where SN sends messages to DN via RN.

Fig. 5 shows our single-relay-aided network considered in this contribution, which consists of a SN, a buffer-aided RN and a DN. The distances between corresponding pairs of nodes are *dSR* and *dRD.* Before explaining more about the details of this paper, we list the assumptions relevant to the physical layer schemes as below:

- The classic Decode-and-Forward (DF) protocol is employed for relaying the signals;
- Each node is capable of adjusting its transmit power between zero and the maximum transmit power *Pmax* for ensuring that the required SNR of ~Th is achieved at the receiver;
- The signals are transmitted on the basis of TSs having duration of *T* seconds;
- The channels are assumed to experience independent block-based flat Rayleigh fading, where the complex valued fading envelope of a hop remains constant within a TS, but it is independently faded for different TSs;
- The path loss is assumed to obey the negative exponential law of *d-a,* where *a* is the path loss exponent;
- The instantaneous CQ of TS t between each node pairs is denoted by ~SR, and ~RD. The instantaneous transmit power of each node £RD or £RD can then be calculated with the of *f£* == 9.895 X 10-05 and the noise power for *N == 10-14W* which corresponds to a receiver sensitivity of -110 *dBm.*

A. Channel Selection Criteria

Our goal is to activate that particular transmitter, which minimizes the expected end-to-end Packet-Energy-Dissipation (PED). Let us define that the total PED of the SN-RN-DN route is the sum of that in each hop. When the SN-RN channel is activated, the PED of the SN-RN hop *(£SR)* and of the RNDN hop *(£RD)* takes place in two different Time Slots (TSs). Although *£SR* may be known based on the current channel condition, *£RD* of the RN-DN hop is unknown in the current TS. Therefore, we use the expected PED *£RD* for estimating *£RD.* Hence, when SN-RN channel is activate in TS t, the expected end-to-end PED.

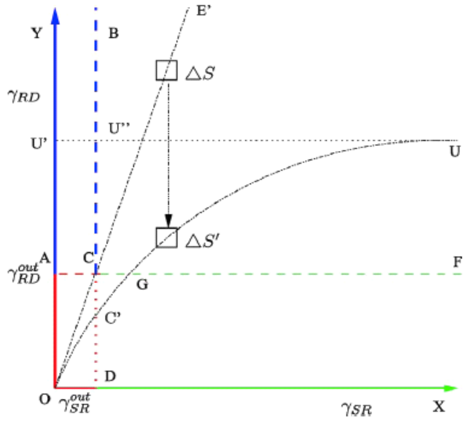

Fig. 6. A plane in CPS which shows that the channel selection is only between SN-RN hop and RN-DN hop.

B. The concept of Channel Probability Space Division

The analysis starts from the concept of the CPS. From Fig. 6, assuming that there is a two-dimensional space §, a specific point associated with the coordinate in § represents the corresponding instantaneous channel condition of the system, hence § represents the CPS of the system. The outage SNR-threshold associated with each coordinate dissects each coordinate into two segments, hence § is cut into 2^2 == 4 subspaces. Fig. 6 shows the resultant CPS.

C. The Energy Efficiency Factor Effe

Our main assumption is that the number of packets conveyed from SN to RN should be the same as those transmitted from RN to DN, which implies that the SN-RN channel and RN-DN channel should have the same probability of being activated. This assumption is automatically satisfied for *dSR == dRD,* since we have identical channel conditions in both hops. However, since *P SR* may not equals *PRD,* an energy efficiency factor *E f fe* is introduced to balance the activation probability of the SN-RN channel and the RN-DN channel, as seen in Fig. 2. The associated activation process can be applied under diverse channel selection scenarios represented by this system model.

Explicitly, our goal is to find the activation boundary between the region (FCB) of activating the SR and RD links. The specific value of *Effe* can be found using whilst a practical algorithm will be provided for solving these equations in Section III-D for the sake of making energy-efficient channel-activation decisions. In the remainder of this section, *Effe* is considered to be a known parameter.

IV. PERFORMANCE RESULTS

In this section, we build up two network topologies for the sake of illustrating the effect of the RN's position on both the energy dissipation and the OP. More specifically, given the proposed channel selection criteria detailed in Section III-A, the non-linear CPS division method discussed throughout Section III-B to Section III-D can be applied. We set the SN to position (100m, 100m) and the DN to position (900m, 100m). We consider two scenarios, where the RN is set to the position of (400m, 100m) for the first topology, while to the position of (300m, 100m) for the second topology. The effect of the buffer size *B* of the RN is also investigated, which ranges from *B* = 1 to *B* = 256 packets. In all experiments, the parameters of N and *k are N* = -110 dBm and *k* = 9.895 X 10^{-05}.

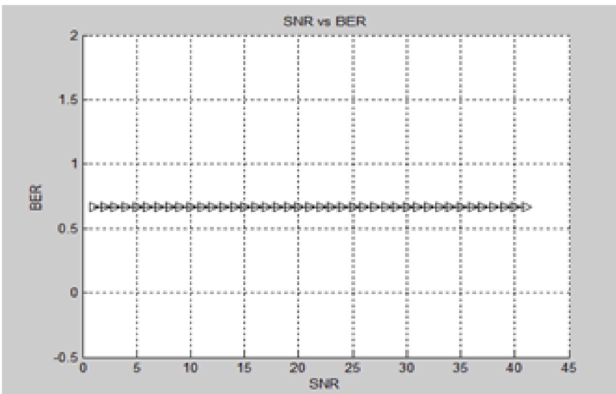

Fig. 7. Output for Signal to Noise Ratio vs Bit Error Rate

Fig. 7 depicts the average capacity of the BER vs. SNR for various numbers of relays. We can clearly see that the average capacity improves as the number of relays increases. We also observe that the rate of improvement decreases as the number of relays increases. Moreover, we notice that the analytical results obtained in Section III are in perfect agreement with the simulation results.

The average delay increases with increasing buffer size. Furthermore, the average delay increases as the number of relays increase. We also observe that buffered AR has an average delay of one packet for all buffer sizes which can be explained by the fact that for SNR = 30 dB buffered AR uses buffering very seldom.

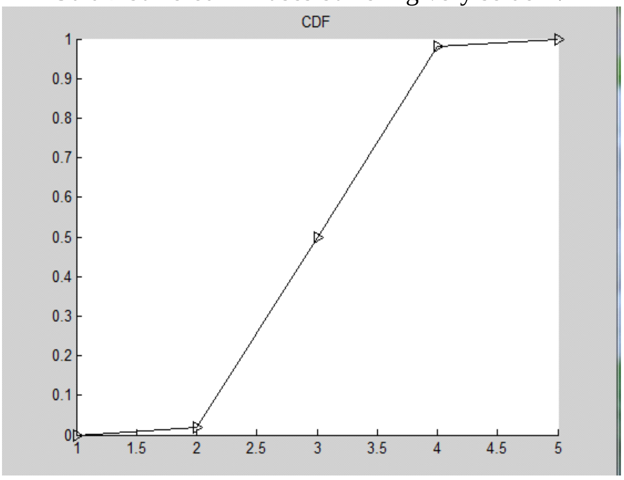

Fig. 8. Output for Cumulative Distribution Function (CDF)

For convenience, "normalized energy dissipation" refers to the "Average normalized end-to-end energy dissipation per packet", which is the optimization objective of this paper. The first topology is represented by 'T1', while the second one by 'T2'. Moreover, 'non-linear-CPS' denotes the proposed buffer-aided transmission scheme associated with our nonlinear CPS division. 'MHDCDF' represents the transmission scheme where the system activates the specific channel, whose SNR cumulative distribution function (CDF) gives the highest ordinate value amongst all the available hops. Finally, 'Bound' represents the theoretical value, which assumes that the RN always has packets to transmit or it is capable of receiving packets in any TS.

V. PROPOSED SYSTEM FOR ENERGY-EFFICIENT

In order to improve the achievable performance of relaying systems, 2D-CPS has been proposed with multi relays, which require the nodes to have a store-and-wait capability. The reason of why 'non-linear-CPS' has the best performance is because it is capable of identifying the highest-quality channel to be activated. To elaborate a little further, as expected, the energy dissipation and the OP have an inverse relationship, albeit their quantitative relationship is beyond the scope of this paper. Additionally, in our previous contributions, we proposed a transmission activation probability scheme, which relies on temporarily storing the received packets and on activating the specific channel having the highest instantaneous SNR.

The contributions of this paper are summarized as follows:

1. The concept of transmission activation probability space (TAPS) and multi relay is proposed. The three channels form a TAPS, which is divided into four regions, each representing one of the three channels plus an outage region. The boundary of each region is analyzed.

2. The end-to-end normalized energy dissipation, the system's OP and the distribution of packet delay are studied in the context of specific buffer sizes.

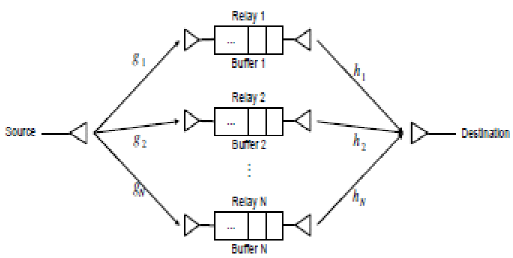

Fig. 9. Relay network with one source, one destination, and N relays where each relay is equipped with a buffer.

A. The Concept of Transmission Activation Probability Space

The TAPS is divided into 8 subspaces based on the reception thresholds of the three channels. The following discussion will consider each of them. Again, a three-node network is considered, where a packet can be transmitted from SN to DN either directly or indirectly via the RN.

1) Firstly, the buffer of a RN may be empty at some instants. In this case, this RN cannot be the transmit node, since it has no data to transmit.

2) Secondly, the buffer of a RN may be full at some instants. Then, this RN cannot be the receive node, since it cannot accept further packets. In these cases, the system has to choose a hop for transmission from a reduced set of hops, which results in an increased energy dissipation and outage probability.

B. The concept of Channel Probability Space Division

The analysis starts from the concept of the CPS. Assuming that there is a two-dimensional space §, a specific point associated with the coordinate in § represents the corresponding instantaneous channel condition of the system, hence § represents the CPS of the system. The outage SNR-threshold associated with each coordinate dissects each coordinate into two segments, hence § is cut into 22 == 4 subspaces. Fig. 6 shows the resultant CPS.

V. CONCLUSION

We proposed a buffer-aided routing scheme relying on our non-linear CPS concept and investigated its performance in terms of both the normalized energy dissipation and the outage probability. A range of formulas have been obtained under the assumption that the packets can be correctly received, provided that the received SNR was in excess of a certain threshold. Our analysis and performance results showed that the proposed scheme results in a significant reduction of the energy dissipation, where the theoretical bound may be closely approached by employing a sufficiently large buffer at the multi RN.

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