# Cooperative Multicast Aided Picocellular Hybrid Information Dissemination in Mobile Social Networks: Delay/Energy Evaluation and Relay Selection

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***Abstract*—A novel hybrid information dissemination scheme is proposed for picocellular systems. At the first stage of our scheme, some of the mobile users (MUs) successfully receive the information of common interest via BS-aided multicast. At the second stage, the information is cooperatively multicast (co-multicast) by the information owners (IOs) in a self-organized ad hoc network until all the MUs receive it. Since limited resources are provided for the second stage of the spontaneous co-multicast, some of the IOs are appointed for relaying the information to the hitherto unserved MUs. Several relay selection protocols are conceived for the sake of improving the performance of our hybrid information dissemination scheme. The simulation results demonstrate that our scheme may reduce the average dissemination delay and the average energy dissipation by $20\%$ and $70\%$, respectively, when compared to the conventional BS aided single-hop multicast. Furthermore, we demonstrate that relying on the IOs associated with the best links plays a crucial role in facilitating spontaneous information dissemination.**

## I. INTRODUCTION

As a benefit of their capability of transmitting the information of common interest to multiple mobile users (MUs), multicast techniques have been widely adopted by network operators for the sake of accommodating the rapid growth of data traffic. However, the conventional BS aided single-hop multicast (BSHM) may suffer from both long delays and excessive energy dissipation, when multicasting information to a large number of MUs [1].

As a remedy, the development of powerful mobile devices equipped with short-range communication techniques, such as WIFI and Bluetooth, makes cooperative multicast (co-multicast) amongst MUs an attractive scheme. In order to enhance the coverage quality, a user that successfully received the message in a previous hop may be randomly selected for further relaying the message to other hitherto unserved users [2]. Multi-stage co-multicast was first studied in [3] for the sake of improving the attainable diversity gain. Moreover, the two-stage co-multicast philosophy was claimed to be more practical than its multi-stage counterpart [4]. The attainable performance of two-stage co-multicast was analysed in [5], while the associated optimum power allocation was characterised in [6]. Furthermore, in [7] and [8], the authors studied relay selection techniques in the context of two-stage co-multicast. Specifically, in [7], the best relay was selected for maximizing the end-to-end co-multicast capacity. In [8], in order to avoid unnecessary power wastage, the relays were activated only if there were unserved nodes within their transmission range.

However, the following drawbacks are commonly shared by the aforementioned contributions [1]-[8]: Firstly, these studies considered stationary users. Secondly, the delay imposed and the energy dissipation required for successfully disseminating the information of common interest to all the MUs were largely ignored by these contributions.

Against the above-mentioned backdrop, our novel contributions are as follows:

*(1) We propose a picocell and co-multicast aided hybrid information dissemination scheme for mobile social networks (MSNs) [9], where all the MUs are willing to share the information of common interest with their peers;*

*(2) The information dissemination scheme is studied both in terms of its delay and the energy required for successfully disseminating the information of common interest to all the MUs;*

*(3) A number of relay selection protocols are proposed for reducing both the delay and energy dissipation in the context of co-multicast aided spontaneous information dissemination.*

The rest of the paper is structured as follows. In Section II, we outline the system model, while a number of relay selection protocols are proposed in Section III, followed by our simulation results in Section IV. Finally, the paper is concluded in Section V.

## II. SYSTEM MODEL

### A. Hybrid information dissemination scheme

As shown in Fig.1, our hybrid information dissemination scheme is comprised of two main stages, which are the BS aided multicast and co-multicast assisted spontaneous dissemination, respectively. The basic time unit is the duration of a frame. All the MUs in MSNs are assumed to be synchronised both with each other and with the BS.

*1) BS aided multicast:* At the first main stage, the BS of a picocell initially multicasts the information of common interest to all the MUs in MSNs. The frame structure employed within this stage is portrayed in Fig.1. At the beginning of the frame, several time slots (TSs) are reserved for pilot

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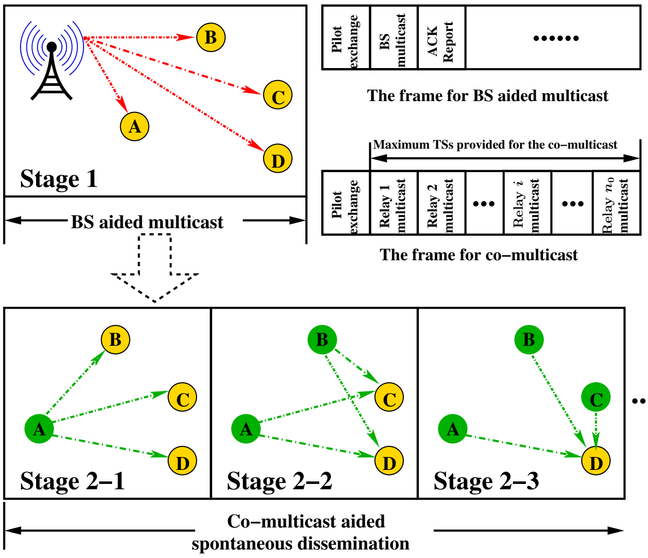

Fig. 1: Hybrid information dissemination scheme

exchange between the MUs and BS. Next, a TS is assigned to the BS for multicasting the information of common interest. Afterwards, several TSs are allocated to the MUs for reporting their feedback. If a MU successfully receives the desired information, an ACK is reported to the BS, otherwise, a NACK is reported. The BS may repeat multicasting the information of common interest in the next frame, if it does not receive any ACK messages during the current frame. Otherwise, the BS aided multicast is completed.

*2) Co-multicast aided spontaneous dissemination:* During the second main stage, the information of common interest is spontaneously disseminated by the information owners (IOs), -namely by the specific users who have already received the information, -to the hitherto unserved MUs (uMUs) via co-multicast techniques until all the MUs in MSNs successfully receive the information. As shown in Fig.1, we have an increasing number of IOs during this stage, and this may substantially speed up the information dissemination process.

During this stage, the BS may play the role of a controller. The frame structure of this stage is also portrayed in Fig.1. At the beginning of the frame, several TSs are reserved for exchanging the relevant pilots between the MUs and the controller. During these TSs, the following tasks are completed:

(a) The IOs report to the controller their willingness of sharing the information of common interest;

(b) The uMUs send requests to the controller for the information of common interest;

(c) All the MUs' geographic positions are collected by the controller[1];

(d) Given the limited resources, the controller decides which IOs are appointed as the relays for further multicasting the information, and then broadcast the decisions to all the IOs and uMUs.

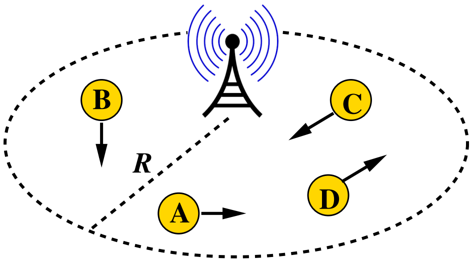

Fig. 2: random mobile networks

In order to avoid any collisions incurred by information multicasters, time-division-multiple-access (TDMA) is introduced. Each information multicaster is allocated a single TS for further multicasting the information of common interest. As shown in Fig.1, only $n_0$ TSs are provided, which indicates that at most $n_0$ IOs are allowed to multicast simultaneously. If the number of IOs exceeds $n_0$, relay selection protocols are activated for the sake of improving the information dissemination performance, which is detailed in Section III.

If the controller does not receive any request from the uMUs at the beginning of the frame, it will inform all the IOs that the information dissemination process is completed.

## *B. Random mobile networks*

We assume that $N$ MUs of MSNs roam in the picocellular coverage area, which is a circular area having a radius of $R$, as shown in Fig.2. Naturally, the BS of the picocell is located at the center of the circular area. In line with the mobility model introduced in [10], the position of the $i$th MU during frame $t$ is denoted by $\mathbf{P}_i(t)$, which represents a stationary and ergodic process having a stationary uniform distribution in the circular area. Moreover, the positions of the different MUs are independent and identically distributed.

## *C. PHY layer descriptions*

*1) Path loss (PL) model:* Given the distance $y$ between a transmitter and receiver pair, which is longer than the reference distance $d_0$ determining the edge of the near-field, the PL model is defined by the following equation

$$\Omega(y) = \frac{P_0}{P_r} = \left(\frac{y}{d_0}\right)^{\kappa}, y \geq d_0, \tag{1}$$

where $P_r$ is the power received at the receiver, $P_0$ is the reference power received at the reference point that is $d_0$ meters (m) away from the transmitter and $\kappa$ is the PL exponent. The free-space PL model is exploited for calculating the PL from the transmitter to the reference point, which is expressed as

$$\Omega_0 = \frac{P_t}{P_0} = \frac{(4\pi)^2 d_0^2}{\lambda^2} = \left(\frac{4\pi d_0}{c/f_c}\right)^2, \tag{2}$$

where $\lambda = c/f_c$ is the wave-length, $c$ is the speed of the light, $f_c$ is the carrier frequency, and $P_t$ is the transmit power. We note that the subscript "t" represents "b" for the BS, and represents "s" for the MUs. Thus, the received reference power $P_0$ is obtained as $P_0 = P_t/\Omega_0$. Unfortunately, (2) is invalid for calculating the PL in the near-field of the transmit antenna.

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[1] Some mobile applications, such as WeChat(http://www.wechat.com/en), have already provided a similar function under the terminology of "look around" to allow mobile devices that are equipped with GPS to exchange their geographic information via a central controller.

As a result, we assume that when the distance $y$ between the transmitter and receiver is shorter than $d_0$, the received power $P_r$ is equal to the transmit power $P_t$. In a nutshell, given an arbitrary distance $y$, the PL model in our system is defined as

$$\Omega(y) = \frac{P_0}{P_r} = \begin{cases} 1/\Omega_0, & 0 \le y < d_0, \\ (y/d_0)^{\kappa}, & y \ge d_0. \end{cases} \tag{3}$$

*2) Small-scale fading:* The small-scale fading is modelled by uncorrelated stationary Rayleigh flat-fading. The channel's amplitude $|h(t)|$ during the $t$th frame, which varies from one frame to another, is a Rayleigh distributed random variable. Consequently, the square of the channel amplitude $|h(t)|^2$ obeys an exponential distribution associated with $E[|h(t)|^2] = 1$. The PDF and CDF of $X = |h(t)|^2$ are $f_X(x) = \exp(-x)$, $F_X(x) = 1 - \exp(-x)$, $x > 0$, respectively.

*3) Transmission rate:* We assume that a packet can only be successfully received if the instantaneously received SNR exceeds a pre-defined SNR threshold $\gamma$. Given the distance $y_{ij}$ between MU $i$ and MU $j$, the successful packet delivery probability $\mu_{ij}$ during a single frame is derived as

$$\mu_{ij} = \text{Prob}\left[\frac{P_{0,s}|h(t)|^2}{N_0 W_s \cdot \Omega(y_{ij})} \ge \gamma\right] = \begin{cases} \exp(-B), & 0 \le y_{ij} < d_0, \\ \exp(-A y_{ij}^{\kappa}), & y_{ij} \ge d_0, \end{cases} \tag{4}$$

where $A = (\gamma N_0 W_s)/(P_{0,s} d_0^{\kappa})$, $B = (\gamma N_0 W_s)/P_s$, $N_0$ is the noise power spectrum density (PSD), $W_s$ is the bandwidth used by the MUs for their transmission, $P_s$ is the transmit power of the MUs and $P_{0,s}$ is the associated received reference power. According to [11], $\mu_{ij}$ is also equivalent to the transmission rate of the link connecting MU $j$ to MU $i$, whose unit is "packets/frame". Following the same methodology, given the distance $y_i$, we may also derive the transmission rate $\mu_i$ of the link connecting MU $i$ to the BS.

## III. Relay Selection Protocols

We assume that there is a set of IOs, $\{IO_i, i = 1, 2, \cdots, n\}$, and a set of uMUs, $\{uMU_j, j = 1, 2, \cdots, N - n\}$, at the beginning of a frame during the information dissemination process. If $n$ is not larger than $n_0$, which is the maximum number of TSs provided by the system for co-multicast, $n$ TSs are allocated to all the IOs. Thus, the controller does not have to carry out any relay selection. However, if $n$ is larger than $n_0$, the controller activates a relay selection protocol and selects $n_0$ relays out of the $n$ IOs for further multicasting the information of common interest. In this section, a suite of six relay selection protocols is designed and their performance is compared in Section IV.

### *A. Random Selection*

Similar to [2], the controller randomly selects $n_0$ IOs out of the $n$ IOs for further multicasting the information of common interest during the frame considered. The controller does not need any knowledge of the geographic positions of the IOs and uMUs, since it relies on a low-complexity random selection. Hence, the performance of the random selection protocol may be considered as a benchmarker for the other relay selection protocols.

### *B. Shortest-Longest-Distance (SLD) selection*

As stated in [7], it is plausible that both the outage and the retransmission performance of multicast are dominated by the weakest link connecting the target to the source. During a frame, the distances spanning from $IO_i$ to all the uMUs construct an array $\{y_{ij}, j = 1, 2, \cdots, N-n\}$. The weakest link of $IO_i$ connects the farthest uMU to $IO_i$, whose length is expressed as $y_{i,\max} = \max\{y_{ij}, j = 1, 2, \cdots, N-n\}$. At the beginning of the frame, the controller calculates the lengths of the weakest link for all the IOs, yielding $\boldsymbol{y}_{\max} = \{y_{i,\max}, i = 1, 2, , \cdots n\}$. Then, it sorts the entries of $\boldsymbol{y}_{\max}$ in ascending order and chooses the specific IOs associated with the first $n_0$ entries of the sorted array $\boldsymbol{y}_{\max}^{sort}$ as the relays to be appointed for further co-multicast. This scheme is referred to as the SLD relay selection protocol.

### *C. Shortest-Shortest-Distance (SSD) Selection*

In our information dissemination scheme, the number of IOs increases during the process. These IOs are all potential multicasters. Having more potential multicasters may provide more opportunities of successfully delivering the information of common interest via co-multicast and this significantly reduces the dissemination delay when all MUs successfully receive the information. Hence, for the sake of reducing the dissemination delay, we have to increase the growth rate of the number of IOs. This growth rate is dominated by the best links connecting the targets to the sources.

During a specific frame, the distances spanning from $IO_i$ to all the uMUs are collected into an array $\{y_{ij}, j = 1, 2, \cdots, N-n\}$. The best link of $IO_i$ connects the nearest uMU to $IO_i$, whose length is expressed as $y_{i,\min} = \min\{y_{ij}, j = 1, 2, \cdots, N-n\}$. At the beginning of the frame, the controller calculates the lengths of the best link for all the IOs, yielding $\boldsymbol{y}_{\min} = \{y_{i,\min}, i = 1, 2, , \cdots n\}$. In order to optimally select the IOs, which are likely to result in the highest growth rate of the number of IOs, the controller sorts the entries of $\boldsymbol{y}_{\min}$ in ascending order and then chooses the particular IOs associated with the first $n_0$ entries of the sorted array $\boldsymbol{y}_{\min}^{sort}$ as the relays to be used for further co-multicast. This scheme is termed as the SSD relay selection protocol.

### *D. Shortest-Sum-Distance (SSUMD) Selection*

Given $\{y_{ij}, j = 1, 2, \cdots, N - n\}$, namely all the distances spanning from all the uMUs to $IO_i$, we define the probability that all the uMUs successfully receive the information of common interest, when $IO_i$ is the information multicaster as

$$p_i = \prod_{j=1}^{N-n} \mu_{ij} \approx \prod_{j=1}^{N-n} \exp(-A y_{ij}^{\kappa}) = \exp\left(-A \sum_{j=1}^{N-n} y_{ij}^{\kappa}\right), \tag{5}$$

where $\mu_{ij}$ is defined in (4). In a practical scenario of $d_0 = 1$ m and when the radius of the picocell is $R = 200$ m, the probability of the distance between a pair of roaming MUs being shorter than $d_0$ is negligible according to the distance CDF derived in [12]. Thus, the approximate relation of (5) holds. Since $\exp(\cdot)$ is an monotonically increasing function, a lower $d_{i,\text{sum}} = \sum_{j=1}^{N-n} y_{ij}^{\kappa}$ leads to a higher $p_i$ and vice versa.

TABLE I: PARAMETERS OF THE PHY LAYER

| | BS to MUs | MUs to MUs |
|---|---|---|
| Transmit Power | $P_b = 23$ dBm | $P_s = 4$ or 0 dBm |
| Carrier Freq | $f_{c,b} = 2$ GHz | $f_{c,s} = 2.4$ GHz |
| Bandwidth | $W_b = 100$ MHz | $W_s = 10$ MHz |
| Noise PSD | $N_0 = -174$ dBm/Hz ($20^o C$) | |
| SNR Threshold | $\gamma = 10$ dB | |
| PL Model | $d_0 = 1$ m, $\kappa = 3$ | |

If the PL exponent $\kappa$ is taken into account by the controller, then at the beginning of a specific frame, the controller calculates $d_{i,\text{sum}}$ for all the IOs, yielding $\boldsymbol{d}_{\text{sum}} = \{d_{i,\text{sum}}, i = 1, 2, , \cdots n\}$. In order to optimally select the IOs having the lowest $d_{i,\text{sum}}$, the controller sorts the elements of the array $\boldsymbol{d}_{\text{sum}}$ in ascending order and chooses the specific IOs corresponding to the first $n_0$ entries of the sorted array $\boldsymbol{d}_{\text{sum}}^{sort}$ as the relays to be appointed for further co-multicast. This scheme is referred to as the SSUMDE relay selection protocol.

If $\kappa$ is set to one by the controller, instead of $d_{i,\text{sum}} = \sum_{j=1}^{N-n} y_{ij}^{\kappa}$, the controller then calculates $d'_{i,\text{sum}} = \sum_{j=1}^{N-n} y_{ij}$ for all the IOs, yielding $\boldsymbol{d'}_{\text{sum}} = \{d'_{i,\text{sum}}, i = 1, 2, , \cdots n\}$. Then, it sorts the elements of the array $\boldsymbol{d'}_{\text{sum}}$ in ascending order, and chooses the specific IOs corresponding to the first $n_0$ entries of the sorted array $\boldsymbol{d'}_{\text{sum}}^{sort}$ as the relays to be appointed for further co-multicast. This scheme is termed as the SSUMD relay selection protocol.

### *E. Highest-Sum-Rate (HSUMR) Selection*

Given $\{y_{ij}, j = 1, 2, \cdots, N-n\}$, which is comprised of the distances spanning from all the uMUs to $IO_i$, we define the sum rate, when $IO_i$ is the information multicaster as

$$\mu_{i,\text{sum}} = \sum_{j=1}^{N-n} \mu_{ij} \approx \sum_{j=1}^{N-n} \exp(-A y_{ij}^{\kappa}). \tag{6}$$

At the beginning of the frame considered, the controller calculates the above sum rates for all the IOs, yielding $\boldsymbol{\mu}_{\text{sum}} = \{\mu_{i,\text{sum}}, i = 1, 2, , \cdots n\}$. In order to optimally select the IOs yielding the highest sum rates, the controller sorts the entries of the array $\boldsymbol{\mu}_{\text{sum}}$ in descending order and chooses the particular IOs corresponding to the first $n_0$ entries of the sorted array $\boldsymbol{\mu}_{\text{sum}}^{sort}$ as the relays for further co-multicast. This scheme is termed as the HSUMR relay selection protocol.

## IV. Numerical Results

The parameters of the PHY layer are presented in TABLE I. For the transmission from the MUs to MUs, the parameters are in line with Bluetooth and WIFI, while for the transmission from the BSs to MUs, the parameters are in line with the LTE-Advanced standard [13]. The radius of the picocell is set to $R = 200$ m and all the MUs of MSNs roam in this circular area. The BS is located at the center of the circular area.

The following two performance metrics of our hybrid information dissemination scheme are evaluated by simulation. The first one is the average information dissemination delay when all the MUs in the picocell receive the information of common interest, quantified in terms of the number of frames. The second one is the average energy dissipation until the information dissemination is completed, which is quantified in terms of "mW*Frame". In order to obtain reliable results, we repeatedly run the simulation in MATLAB 10 000 times. The performance of the conventional BSHM is also presented as a benchmarker.

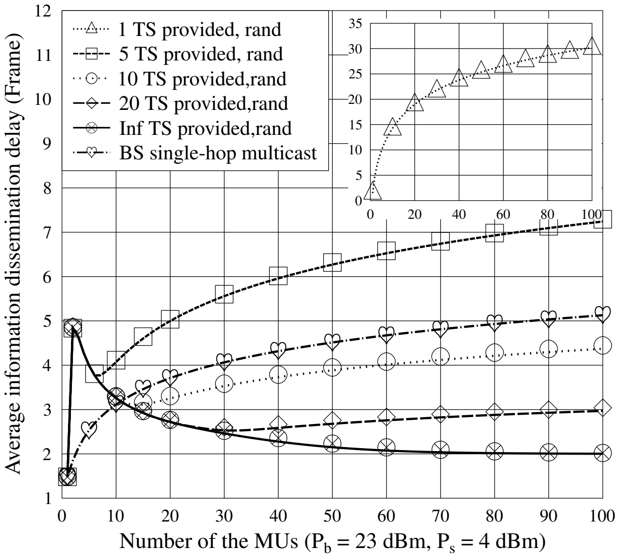

Fig. 3: Average dissemination delay under random selection

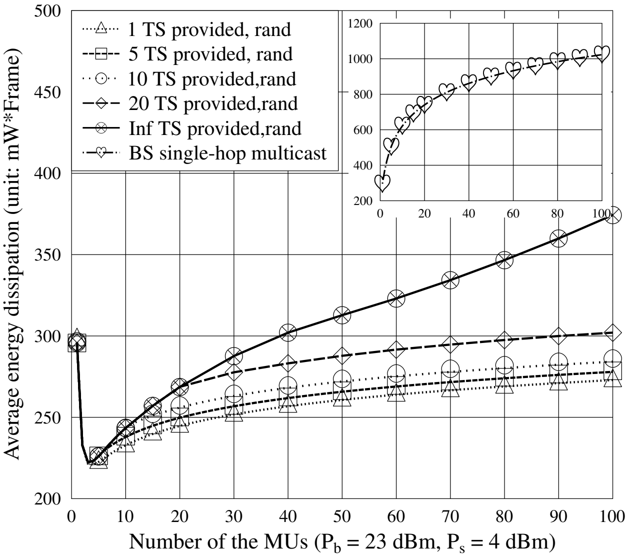

Fig. 4: Average energy dissipation under random selection

### *A. Maximum number of TSs provided for co-multicast*

The transmit power of MUs is $P_s = 4$ dBm, and the number $N$ of MUs in the picocell, varies from 1 to 100. Again, a low-complexity random relay selection protocol is invoked. As shown in Fig.3, the average delay of the BSHM continuously increases as $N$ increases. The curve associated with $n_0 = 1$ exhibits a similar trend to the BSHM, but its values are much higher, since $P_s$ is much lower than $P_b$. However, for $n_0 = \{5, 10, 20, \infty\}$ the average information dissemination delay first increases until reaching its peak, before it subsides. If the system is only able to provide a limited number of TSs for co-multicast, say $n_0 = \{5, 10, 20\}$,

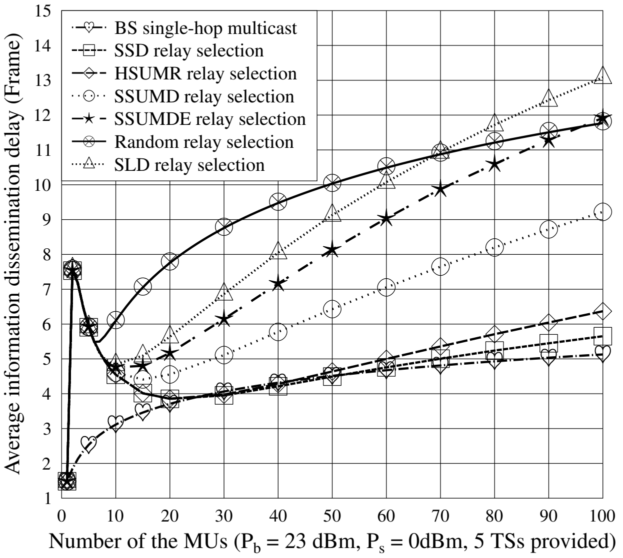

Fig. 5: Average dissemination delay when 5TSs provided

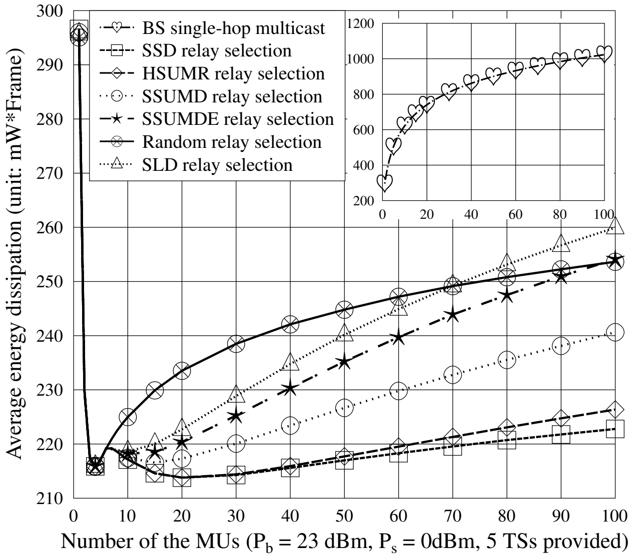

Fig. 6: Average energy dissipation when 5TSs provided

following a minimum, the average dissemination delay may increase steadily again as we further increase $N$. However, if the number of TSs used for co-multicast tends to infinity, the average information dissemination delay may tend to 2 frames, as $N$ tends to infinity. Furthermore, if more TSs are provided for co-multicast, the average dissemination delay is significantly reduced. As shown in Fig.3, for $n_0 = \infty$ and $N = 100$, the average delay is reduced by 60% compared to the BSHM benchmarker.

Fig.4 portrays the average energy required for disseminating the information of common interest to all the MUs in the picocell. The average energy dissipation first decays, as we increase $N$ from one to two, and then it steadily increases, as we further increase $N$. As presented in Fig.4, if we allow more IOs to simultaneously multicast, which is represented by a higher $n_0$ value, more energy is dissipated, but still remains lower than the BSHM benchmarker.

Furthermore, according to Fig.3, our scheme associated with $n_0 = 10$ may reduce the average delay by about 20% if $N = 100$, compared to the BSHM benchmarker. Furthermore, the average energy dissipation can be reduced by about 70% according to Fig.4. This example demonstrates that, given an appropriate $n_0$, our hybrid information dissemination scheme is capable of reducing the dissemination delay, while simultaneously reducing the energy dissipation.

### B. *Different relay selection protocols*

In order to compare the performance of the different relay selection protocols proposed in Section III, the transmit power of the $MUs$ is set to $P_s = 0$ dBm, while the maximum number of TSs provided for co-multicast is set to $n_0 = 5$.

As shown in Fig.5, compared to random relay selection, a significantly improved performance is achieved, when the various relay selection protocols are chosen by taking into account the specific geographic positions of the IOs and uMUs. Since the IOs associated with the best links are selected as the relays for further multicasting the information of common interest under the SSD and HSUMR protocols of Sections III-C and III-E, these two protocols achieve the best performance. Compared to the random relay selection, SSD results in nearly 50% delay reduction, whilst simultaneously achieving nearly the same delay as the BSHM.

As presented in Fig.5, the SSUMD protocol of Section III-D outperforms SSUMDE of Section III-D, because SSUMD has a higher probability of activating the IOs associated with the best links. Let us consider a simple example, supporting two uMUs with the aid of two IOs. The distances spanning from $IO_1$ to both the uMUs are $\{1, 90\}$ m, while those from $IO_2$ to both the uMUs are $\{50, 50\}$ m. According to the SSUMDE protocol, $IO_2$ is selected as the relay, while SSUMD prefers $IO_1$. Since $IO_1$ has the best link, the information may be disseminated more promptly if $IO_1$ is selected. Compared to the SLD protocol of Section III-B, the SSUMDE protocol has a higher probability of activating IOs associated with the best link. Let us assume that the distances spanning from $IO_1$ to both the uMUs are $\{1, 90\}$ m, whilst those from $IO_2$ to both the uMUs are $\{50, 85\}$ m. Then the SSUMDE protocol selects $IO_1$ as the relay, while the SLD protocol selects $IO_2$ as the relay. Hence, as demonstrated in Fig.5, the SSUMDE protocol outperforms the SLD.

We can observe from Fig.6 that the SSD protocol saves the most energy. Compared to random relay selection, if we have $N = 100$ MUs in the picocell, the average energy dissipation is reduced by 12.3%, when the SSD protocol is implemented. Furthermore, compared to the BSHM, the average energy dissipation is reduced by 75% under the SSD protocol.

## V. Conclusions

In this paper, we proposed a picocell and co-multicast aided hybrid information dissemination scheme for MSNs. As presented in Fig.3-4, compared to the conventional BS aided single-hop multicast, our hybrid information dissemination scheme is capable of significantly reducing both the information dissemination delay as well as the energy dissipation. Furthermore, several relay selection protocols were designed by following different principles, including the SLD, SSD, SSUMD, SSUMDE, as well as HSUMR of Section III. The simulation results of Fig.5-6 demonstrated that the SSD protocol exhibits the best performance. Furthermore, we demonstrated that appointing the IOs associated with the best links as the relays is capable of significantly improving the information dissemination performance.

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