Spreading Information in Mobile Wireless Networks

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***Abstract*—Device-to-device (D2D) communication enables us to spread information in the local area without infrastructure support. In this paper, we focus on information spreading in mobile wireless networks where all nodes move around. The source nodes deliver a given information packet to mobile users using D2D communication as an underlay to the cellular uplink. By stochastic geometry, we derive the average number of nodes that have successfully received a given information packet as a function of the transmission power and the number of transmissions. Based on these results, we formulate a redundancy minimization problem under the maximum transmission power and delay constraints. By solving the problem, we provide an optimal rule for the transmission power of the source node.**

Keywords*—*Information spreading, mobility, redundancy minimization, mobile wireless network.

I. Introduction

Near field communication (NFC) technologies enable devices in close proximity to exchange mutual information without any infrastructure support. Device-to-device (D2D) communication in 3GPP LTE (Long Term Evolution) also facilitates information exchange between adjacent devices. We call this *information spreading* throughout this paper. Such information spreading via wireless networks boosts various services, for example, mobile marketing and advertisement in local areas [1], [2].

For efficient information spreading, an accurate prediction on the number of nodes that have successfully received a given information packet as time goes is necessary. A classical research issue in computer science is to calculate the *cover time* that defines the expected number of transmissions (or hops) until all nodes in a given network receive a specific packet [3]. Applications of the cover time analysis include searching/querying, routing, membership services and group based communications. The cover time analysis has been limited to the wired or the static network, though it is extended to quantify the end-to-end delay in mobile ad hoc networks [4].

The aggregated interference analysis is necessary to calculate the probability that a node receives a specific packet successfully. In [5], [6], the authors modeled wireless networks using a stochastic point process and analyzed SIR (signal-to-interference-ratio) distribution and outage probability. The mutual interference between cellular users and D2D should be considered in D2D underlaying cellular network scenario.

Some previous works dealt with the information spreading in ad hoc networks when all nodes participate as relay nodes. The authors in [7] proposed a selective forwarding method based on the minimum connected dominating set (CDS). A reliable localized broadcast protocol using location information and acknowledgements was proposed in [8]. In many cases, however, mobile nodes (users) have no incentive to relay the received packet.

In this paper, we focus on the information spreading in mobile wireless networks where all nodes move around and there is no relay. Node mobility improves the capacity of wireless networks [9]. It also brings positive effects on the information spreading. Moving nodes can deliver information anywhere by direct transmission. On the other hand, this may cause packet *delay*, which is an important parameter in the information spreading.

Another parameter is the number of *redundant receptions*[1] (i.e., waste of resources). If the maximum transmission power is not limited, we increase the transmission power as large as the target number of nodes in the network can receive a given information packet at once. In practice however, the power constraint requires multiple transmissions when delivering the information packet to the target nodes.

Some information spreading scenarios allow large delay. Thereby, reducing the redundant receptions is more important than delivering the information packet quickly. From this, we have the following questions regarding optimal information spreading in mobile wireless networks:

- How many transmissions are required for delivering a given information packet to a certain percentage of nodes in the network?
- What is the optimal transmission power for minimizing the total number of redundant receptions, while keeping the delay within a reasonable level?

This paper is organized as follows. In Section II, we describe the system model and introduce the redundancy minimization problem. Then, we describe the mobility model and derive the average number of MUs that have successfully received a given information packet as a function of the transmission power and the number of transmissions in Sections III and IV. We solve the redundancy minimization problem and provide the optimal transmission power and the optimal number of transmissions in Section V (Proposition 4 and 5).

II. Redundancy Minimization Problem in Information Spreading

Consider a cellular network composed of N_b base stations (BSs), N_u mobile users (MUs) and N_s mobile source nodes. The source nodes deliver a given information packet

[1]The term “redundant reception” means that a node receives the same packet multiple times.

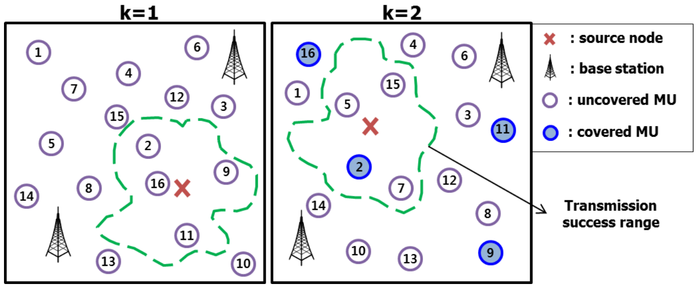

Fig. 1. System model. (Numbers are inserted to discriminate the MUs.)

to MUs in every T second using D2D communication as an underlay to the cellular uplink. In general, cooperative relaying like flooding is effective for spreading information. However, overwhelming transmission due to relaying may cause serious interference to the cellular network. Hence, source nodes get around to impart the information, where MUs are also moving around the entire network. The transmission power of source nodes, μ, is limited by $\overline{\mu}$, and the transmission power of MU is normalized by 1.

The fading between a source node located at point x and a typical MU (typical receiver) located at the origin is h_x, and the fading between an MU who transmits for the cellular uplink at point y and the typical MU is g_y. These are assumed to be i.i.d. exponential random variables with the unit mean (Rayleigh fading). Also, the path loss function is given by $l(x) = \|x\|^{-\alpha}$, where $\alpha > 2$ is the path loss exponent. For simplicity, we assume that $\alpha = 4$. Then, for a typical mobile user, a received power of the signal from the source node is expressed as $\mu h_x \|x\|^{-\alpha}$. Assuming the network is interference-limited, the SIR (signal-to-interference-ratio) at the typical MU is given by:

$$SIR = \frac{\mu h_x \|x\|^{-\alpha}}{\sum\limits_{y \in C} g_y \|y\|^{-\alpha} + \sum\limits_{z \in S \setminus \{x\}} \mu h_z \|z\|^{-\alpha}},$$

where C and S denote the set of cellular uplink MUs and source nodes, respectively. For a given target SIR β, a typical MU successfully receives packets from a corresponding source node if SIR is greater than or equal to β. We denote by p_{suc} the probability that the typical MU successfully receives packets.

Let us define that an MU is *covered* if the MU receives an information packet from a source node at least once. The number of covered MUs by the end of the k-th time slot is a random variable, denoted as N_k. The random variable M_k denotes the number of MUs whose SIR is not less than β at the k-th time slot, out of which $\hat{M}_k$ is the number of MUs that have been already covered. For example, in the left figure of Fig. 1, $M_1 = 4$, $\hat{M}_1 = 0$, $N_1 = 4$. In the right figure, $M_2 = 5$, $\hat{M}_2 = 1, N_2 = 8$.

During the spreading process, redundant receptions may occur, which we need to minimize as formulated below:

$$\begin{aligned} (\mathbf{P}) \quad & \min_{\mu, k} \quad f(\mu, k), \\ & \text{s.t.} \quad \frac{E[N_k]}{N_u} \geq \gamma, \\ & \qquad 0 \leq \mu \leq \bar{\mu}, \ 1 \leq k \leq \bar{k}. \end{aligned}$$

The objective function $f(\mu, k)$ denotes the number of redundant receptions. Note that the control parameters are μ and k, which means that we jointly determine how large the transmission power is set and how many times the information packet is repeatedly transmitted. The first constraint requires that the ratio of the covered MUs should be higher than or equal to a target value γ. The second constraint determines the maximum transmission power. The last constraint says that the number of required transmission slots (i.e., delay) should be less than $\bar{k}$ slots.

III. Mobility Model: Homogeneous Condition

To describe node mobility, we define the *homogeneous condition* [4] as follows:

Definition 1: *If $E[M_k] = N_u p_{suc}$ and $E\left[\frac{\hat{M}_k}{M_k}\right] = E\left[\frac{N_{k-1}}{N_u}\right]$ for all k, then node mobility is said to satisfy the homogeneous condition.*

To understand the homogeneous condition, let us regard covered MUs as molecules of a chemical *solute*. Then, the homogeneous condition resembles a homogeneous solution where the solute concentrations in any location are the same owing to the high speed of molecular movement. Definition 1 means that all nodes should be uniformly distributed and the ratio of covered MUs in any segmental area of the network should be the same with that ratio of the whole network to satisfy the homogeneous condition. The second figure of Figure 1 is an example satisfying the condition. In the figure, one of the four MUs is covered in the transmission range and four of the sixteen MUs are covered in the whole network.

Proposition 1: *If all nodes are randomly distributed in the whole area and move anywhere independently of their previous positions (i.e., the i.i.d. mobility model [10]), then the network satisfies the homogeneous condition.*

Proof: If all nodes have the i.i.d. mobility, they are uniformly distributed in the network at each time slot. The SIR of an arbitrary MU is larger than β with the same probability p_{suc}. Thus, M_k follows a binomial distribution $B(N_u, p_{suc})$, and $E[M_k] = N_u p_{suc}$.

Moreover, the distribution of $[\hat{M}_k | M_k, N_{k-1}]$ follows a binomial distribution $B(M_k, N_{k-1}/N_u)$, because the position of node is independent of its previous position. Using the total probability theorem, we calculate $E[\hat{M}_k / M_k]$ as follows:

$$\begin{aligned} E\left[\frac{\hat{M}_k}{M_k}\right] &= E_{N_{k-1}}\left[E_{M_k}\left[E_{\hat{M}_k}\left[\frac{\hat{M}_k}{M_k} | M_k, N_{k-1}\right] | N_{k-1}\right]\right] \\ &= E_{N_{k-1}}\left[E_{M_k}\left[\frac{1}{M_k}\frac{M_k N_{k-1}}{N_u} | N_{k-1}\right]\right] = E_{N_{k-1}}\left[\frac{N_{k-1}}{N_u}\right]. \end{aligned}$$

■

Another mobility model that satisfies the homogeneous condition is the random direction model [11] with high relative speed[2]. In the random direction model, all nodes' speeds and moving directions are chosen randomly and independently of other nodes. If an MU has high relative speed that is enough to reach any point in the network during T, the random direction

[2] By the relative speed, we mean the moving speed relative to the transmission interval T.

mobility model is equivalent to the i.i.d. mobility model and satisfies the homogeneous condition, which we will verify by means of simulations in Figure 2. Hereafter, we assume that our considered network satisfies the homogeneous condition.

IV. Number of Covered Mobile Users

In this section, we derive the average number of covered MUs, $E[N_k]$. We consider two transmission modes; *broadcast* and *unicast*. In the broadcast mode, all MUs whose SIR is higher than β receive the information packet. In the unicast mode, the source intends to deliver the packet to the nearest MU.

To derive the average number of covered MUs, we need to know the successful transmission probability p_{suc}, for which we model the aggregate interference by stochastic geometry and shot-noise theory [5], [6].

A. Unicast Mode

The average number of covered MUs in the unicast mode, $E[N_k^U]$, is expressed in the following proposition[3]:

Proposition 2: *In the unicast mode, the average number of covered MUs by the end of the k-th time slot is*

$$\begin{aligned} E\left[N_k^U\right] &= N_u\left[1-\left(1-\frac{N_s}{N_u}p_i p_{suc}^U\right)^k\right], \\ \text{where } p_{suc}^U &= \frac{N_u}{N_u+\frac{\pi}{2}\frac{\sqrt{\beta}}{\sqrt{\mu}}N_b+\frac{\pi}{2}N_s\sqrt{\beta}}, \\ p_i &= 1-\frac{N_b}{N_u}\left(1-\left(1+3.5^{-1}N_u/N_b\right)^{-3.5}\right). \end{aligned}$$

Proof: We approximate p_{suc}^U by assuming the network as a Poisson network, which means that BSs, MUs and the sources are located according to independent homogeneous Poisson point processes Φ_b, Φ_u and Φ_s, respectively. Also, we set the intensities as $\lambda_b = N_b/S$, $\lambda_u = N_u/S$ and $\lambda_s = N_s/S$, where S denotes the area of the network. Because the source nodes deliver the information using D2D communication as an underlay to the cellular uplink, the interference from cellular communications should be considered. To model the interference, we regard the intensity of cellular uplink MUs as the intensity of the BSs (full load). Then, we obtain p_{suc}^U as follows:

$$\begin{aligned} p_{suc}^U &= E_X\left[\Pr\left[SIR\geq\beta \,|\, X=x\right]\right] \\ &= \int_0^\infty \mathcal{L}_I^U\left(\frac{\beta x^\alpha}{\mu}\right)2\pi\lambda_u x e^{-\lambda_u\pi x^2}dx, \end{aligned} \tag{1}$$

$$\begin{aligned} \mathcal{L}_I^U(z) &= \exp\left(-2\pi\lambda_b\int_0^\infty\left(1-\frac{1}{1+zx^{-\alpha}}\right)x\,dx\right) \\ &\times \exp\left(-2\pi\lambda_s\int_y^\infty\left(1-\frac{1}{1+z\mu y^{-\alpha}}\right)y\,dy\right). \end{aligned} \tag{2}$$

$\mathcal{L}_I^U(z)$ is the Laplace transform of random variable I where the aggregated interference I is composed of two independent terms: the interference from the cellular uplink MUs and the interference from the sources except the desired signal. The term s_o denotes the nearest source. From (1) and (2), the successful transmission probability for unicast mode is expressed as follows:

$$p_{suc}^U = \frac{\lambda_u}{\lambda_u+\frac{\pi}{2}\frac{\sqrt{\beta}}{\sqrt{\mu}}\lambda_b+\frac{\pi}{2}\lambda_s\sqrt{\beta}}. \tag{3}$$

Also, we need to know the idle probability of an arbitrary MU, p_i, because the source cannot cover the MU if the MU communicates with a BS. By the Proposition 2 in [12], the probability (p_i) that a randomly chosen MU is not assigned a resource block at a given time is expressed as follows:

$$p_i = 1-\frac{N_b}{N_u}\left(1-\left(1+3.5^{-1}N_u/N_b\right)^{-3.5}\right). \tag{4}$$

Then, we get the recurrence relation for $E[M_k^U-\hat{M}_k^U]$ and solve it as follows:

$$\begin{aligned} &E\left[M_k^U-\hat{M}_k^U\right] \overset{(a)}{=} E\left[M_k^U\right]E\left[1-\frac{\hat{M}_k^U}{M_k^U}\right] \\ &\overset{(b)}{=} \frac{N_u\lambda_s}{\lambda_u}p_i p_{suc}^U E\left[1-\frac{N_{k-1}^U}{N_u}\right] \overset{(c)}{=} \frac{N_u\lambda_s}{\lambda_u}p_i p_{suc}^U\left(1-\frac{N_u\lambda_s}{\lambda_u}p_i p_{suc}^U\right)^{k-1} \end{aligned} \tag{5}$$

In the above equation, (a) follow from independency between the number of MUs and the covered ratio, and the homogeneous condition satisfies (b). By solving the recurrence relation, we achieve (c).

$$E\left[N_k^U\right] = \sum_{i=1}^k E\left[M_i^U-\hat{M}_i^U\right] = N_u\left[1-\left(1-\frac{\lambda_s}{\lambda_u}p_i p_{suc}^U\right)^k\right].$$

■

Proposition 2 indicates that the transmission power of the source has small impact on the average number of the covered MUs. Rather, the probability that an arbitrary MU is the nearest MU from the source, N_s/N_u, is a dominant factor.

B. Broadcast Mode

The average number of covered MUs in the broadcast mode, $E[N_k^B]$, is expressed as the following proposition:

Proposition 3: *In the broadcast mode, the average number of covered MUs by the end of the k-th time slot is*

$$E\left[N_k^B\right] = N_u\left[1-\left(1-p_i p_{suc}^B\right)^k\right],$$

$$\text{where } p_{suc}^B = \frac{N_s}{N_s+\frac{\pi}{2}\frac{\sqrt{\beta}}{\sqrt{\mu}}N_b+N_s\sqrt{\beta}\left(\frac{\pi}{2}-\tan^{-1}\left(\frac{1}{\sqrt{\beta}}\right)\right)}.$$

Proof: Similar to the proof of Proposition 2, we have

$$\begin{aligned} p_{suc}^B &= \int_0^\infty \mathcal{L}_I^B\left(\frac{\beta x^\alpha}{\mu}\right)2\pi\lambda_s x e^{-\lambda_s\pi x^2}dx, \\ \mathcal{L}_I^B(z) &= \exp\left(-2\pi\lambda_b\int_0^\infty\left(1-\frac{1}{1+zx^{-\alpha}}\right)x\,dx\right) \\ &\times\exp\left(-2\pi\lambda_s\int_0^\infty\left(1-\frac{1}{1+z\mu y^{-\alpha}}\right)y\,dy\right). \end{aligned}$$

And the successful transmission probability is expressed as follows:

$$p_{suc}^B = \frac{\lambda_s}{\lambda_s+\frac{\pi}{2}\frac{\sqrt{\beta}}{\sqrt{\mu}}\lambda_b+\lambda_s\sqrt{\beta}\left(\frac{\pi}{2}-\tan^{-1}\left(\frac{1}{\sqrt{\beta}}\right)\right)}. \tag{6}$$

In broadcast mode, the probability that an arbitrary MU is the nearest is not considered, because the source delivers

[3]In this paper, the superscripts U and B represent the unicast mode and the broadcast mode, respectively.

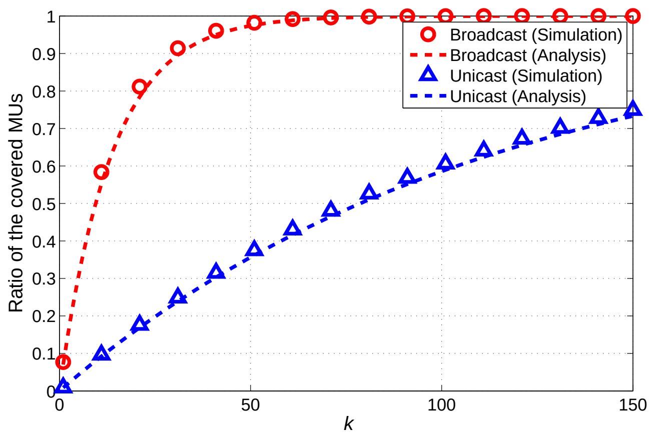

Fig. 2. The average ratio of covered MUs by the end of the k-th time slot in the unicast and broadcast modes. In the simulations, all nodes move according to the random direction mobility model with a speed of 5 m/s. $S = 2000 \times 2000\ m^2$. $N_b = 8$, $N_u = 400$, $N_s = 4$. $\mu = 0.064$. $T = 600s$.

the information packet to the multiple receivers. We get the following results by solving the same recurrence relation as (5):

$$E\left[M_k^B - \hat{M}_k^B\right] = N_u p_i p_{suc}^B \left(1 - N_u p_i p_{suc}^B\right)^{k-1},$$

$$E\left[N_k^B\right] = \sum_{i=1}^{k} E\left[M_i^B - \hat{M}_i^B\right] = N_u \left[1 - \left(1 - p_i p_{suc}^B\right)^k\right].$$

■

Different from the unicast mode, a source can deliver the information to multiple MUs. Hence, the average number of the covered MUs increases rapidly with transmission power. From Propositions 2 and 3, we observe that the broadcast mode is reduced to the unicast mode by taking $p_{suc}^B = (N_s/N_u)\, p_{suc}^U$. Thus, we consider only the broadcast mode in the redundancy minimization problem (Section V).

To verify Propositions 2 and 3, we conducted simulations, where we set the whole area $S = 2000 \times 2000\ m^2$. We set the numbers as $N_b = 8$, $N_u = 400$ and $N_s = 4$, and the transmission power as $\mu = 0.064$. The repeated transmission period $T = 600s$. We use the random direction mobility model [11], where we set the speed of 5 m/s. MUs satisfy the homogeneous condition because they can reach anywhere in the network in a repeated transmission period. Figure 2 shows the results sampled over 10^5 instances, which exactly coincide with Propositions 2 and 3.

V. Optimal Rule for Redundancy Minimization

In this section, we solve the redundancy minimization problem $(\mathbf{P})$. Using the fact that $\hat{M}_k^B$ is equal to the number of redundant receptions caused by the transmission of the source node at the k-th time slot, we derive the average number of redundant receptions by the end of the k-th time slot:

$$f(\mu,k) \overset{(a)}{=} \sum_{i=1}^{k} E\left[M_i^B\right] E\left[\frac{\hat{M}_i^B}{M_i^B}\right] \overset{(b)}{=} N_u p_i p_{suc}^B \sum_{i=1}^{k} E\left[\frac{N_{i-1}^B}{N_u}\right]$$
$$= N_u k p_i p_{suc}^B - N_u \left(1 - \left(1 - p_i p_{suc}^B\right)^k\right). \quad (7)$$

where (a) follows from independency between the number of MUs and the covered ratio, and the homogeneous condition supports (b). Proposition 3 is applied to the last equality. We can rewrite $(\mathbf{P})$ as follows:

$$(\mathbf{P}') \quad \min_{\mu,k} \quad N_u k p_i p_{suc}^B - N_u \left(1 - \left(1 - p_i p_{suc}^B\right)^k\right),$$
$$\text{s.t.} \quad 1 - \left(1 - p_i p_{suc}^B\right)^k \geq \gamma,$$
$$0 \leq \mu \leq \bar{\mu},$$
$$1 \leq k \leq \bar{k}.$$

Mobile devices usually have the ability of dynamically adjusting their transmission power. Thus, we consider two cases: $i)$ the source nodes transmit with a constant power, $ii)$ the source nodes adjust the transmission power in every slot. For each case, we jointly optimize μ and k for $(\mathbf{P}')$. The results are described in the following propositions.

Proposition 4 (Optimum in constant power case):[4] *In the redundancy minimization problem with a constant transmission power, the optimal transmission power (μ^*) and the number of required transmission slots (k^*) are*

$$\mu^* = \frac{\pi^2 {N_b}^2 \beta}{4{N_s}^2 \left(\frac{p_i}{1-(1-\gamma)^{1/k*}} - \kappa - 1\right)^2},$$

$$k^* = \left\lceil \frac{\log(1-\gamma)}{\log\left(1 - p_i N_s \Big/ \left(N_s(1+\kappa) + \frac{\pi}{2}\frac{\sqrt{\beta}}{\sqrt{\mu}} N_b\right)\right)} \right\rceil,$$

where $\lceil x \rceil$ denotes the smallest integer that is larger than or equal to x and $\kappa = \sqrt{\beta}\left(\pi/2 - \tan^{-1}\left(\beta^{-(1/2)}\right)\right)$.

Proof: In $(\mathbf{P}')$, the first constraint should be satisfied with equality because there is no reason to cover more MUs than the target. Therefore, we get the following equation:

$$1 - (1 - p_i p_{suc})^k = \gamma \ \rightarrow \ p_i p_{suc}^* = \left(1 - (1-\gamma)^{1/k}\right). (8)$$

Moreover, the objective function can be transformed into as follows:

$$\min_{\mu,k} \quad N_u k p_i p_{suc}^B - N_u \left(1 - \left(1 - p_i p_{suc}^B\right)^k\right)$$
$$\rightarrow \min_{\mu,k} \quad N_u k p_i \left(1 - (1-\gamma)^{1/k}\right) - N_u \gamma.$$

The second term of the objective function in $(\mathbf{P}')$ becomes $N_u \gamma$, which is independent of the control variables μ and k. Then, we have only to minimize the first term $N_u k p_i \left(1 - (1-\gamma)^{1/k}\right)$ by Equation (8). Note that $N_u k p_i \left(1 - (1-\gamma)^{1/k}\right)$ is an increasing function of k for $0 < \gamma \leq 1$. Therefore, k^* should be the smallest integer that satisfies the second constraint in $(\mathbf{P}')$. Using this and Equation (8), we can calculate k^* and μ^*. ■

According to Proposition 4, if the maximum transmission power is sufficiently large or is not limited, then the optimal rule is to increase the transmission power so large as to cover the target number of MUs at once. On the other hand, if the maximum transmission power is limited, μ^* is the largest

[4]Propositions 4 and 5 exclude the case that γ is equal to one because it requires the infinite number of transmission slots.

one below the maximum transmission power $\bar{\mu}$, which makes corresponding k^* be the smallest integer.

Proposition 5 (Optimum in dynamic power control case): *In the redundancy minimization problem with dynamic power control, the optimal transmission power (μ^*) and the number of required transmission slots (k^*) are*

$$\mu^* = \begin{cases} \overline{\mu} & for\, k < k^* \\ \frac{\pi^2 N_b{}^2 \beta \left[(1-p_i \overline{p_{suc}})^{k^*-1}+\gamma-1\right]^2}{4 N_s{}^2 \left[(1-\gamma)(1+\kappa)+(1+\kappa-p_i)(1-\overline{p_{suc}})^{k^*-1}\right]^2} & for\, k = k^* \end{cases},$$

$$k^* = \left\lceil \frac{\log(1-\gamma)}{\log(1-p_i \overline{p_{suc}})} \right\rceil,$$

where $\overline{p_{suc}} = N_s \Big/ \left(N_s(1+\kappa) + \frac{\pi}{2}\frac{\sqrt{\beta}}{\sqrt{\overline{\mu}}} N_b \right)$.

Proof: Let μ_t and R_t denote the transmission power of the source node and the covered ratio of the network at t-th time slot, respectively. Considering t-th and $(t+1)$-th time slots, it is obvious that R_{t+1} is larger or equal than R_t. Then, we can get the following equation:

$$p_{suc}(\mu_t) N_u (1-R_t) = p_{suc}(\mu_{t+1}) N_u (1-R_{t+1})$$

where $p_{suc}(\mu_t)$ denotes the successful transmission probability which corresponds to μ_t. The left-hand side of the equation means the number of covered MUs at t-th time slot, and the right-hand means the number of covered MUs at $(t+1)$-th time slot. Hence, the equation shows the relationship among the transmission powers and the covered ratios to cover the same number of MUs in each of two consecutive time slots. We can rearrange the equation as

$$\frac{p_{suc}(\mu_{t+1})}{p_{suc}(\mu_t)} = \frac{1-R_t}{1-R_{t+1}}.$$

It is obvious that right-hand side of the equation is not less than 1. Hence, μ_{t+1} is larger or equal than μ_t to satisfy the equality, because the successful transmission probability is an increasing function of μ_t. Furthermore, we can obtain the following relationship:

$$p_{suc}(\mu_t) N_u R_t \le p_{suc}(\mu_{t+1}) N_u R_{t+1}.$$

It means that the redundancy must be not less than that of the previous time slot to cover the same number of MUs at a certain time slot. With a given target number of covered MUs, therefore, the maximum power is optimal for the redundancy minimization except the last time slot. At the last time slot, the transmission power that achieves the target coverage ratio is optimal, which can be obtained from $X_{k^*} = \gamma - \left[1-(1-p_i\overline{p_{suc}})^{k^*-1}\right]$. ■

In the information spreading with dynamic power control, the number of required transmission slots is the same as that of the constant power case. The optimal power μ^* is $\bar{\mu}$ except the last slot in which the power that equals the average ratio of covered MUs to γ.

VI. Conclusions

We focused on the redundancy minimization problem for information spreading in mobile wireless networks. By stochastic geometry, we derived the probability that the source node successfully delivers a given information packet to the mobile user where the mutual interference between device-to-device communication and the cellular communication exist. Using this, we derived the average number of covered MUs as a function of the transmission power and the number of transmissions for two cases; unicast and broadcast. In unicast mode, the probability that an arbitrary selected MU is the nearest and have not been covered is a dominant factor for receiving the information. Hence, an algorithm for selecting uncovered MU is important to design the unicast information spreading system. The received signal to interference ratio is more important in broadcast mode. Hence, interference management schemes are more important in broadcast system.

In addition, we provided the optimal transmission power and the optimal number of transmissions in two cases: the sources transmit with a constant power and the sources can adjust the power in every time slot. If the source nodes cannot adjust their transmission power due to the simplicity of the device, then the maximum power is the optimal to minimize redundant receptions. Maximal power transmission is also optimal, even though the sources are able to adjust transmission power in every time slot. In this case, however, the sources reduce the transmission power in the last time slot, not to exceed the target coverage ratio.

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