Master's Thesis
석사 학위논문

Performance Analysis for Full-Duplex Random Access in Distributed Networks

Dongwoo Yeom (염 동 우 廉 東 佑)

Department of Information and Communication Engineering

정보통신융합공학전공

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Advisor : Professor Ji-Woong Choi

Co-advisor : Professor Hongsoo Choi

by

Dongwoo Yeom

Department of Information and Communication Engineering

DGIST

A thesis submitted to the faculty of DGIST in partial fulfillment of the requirements for the degree of Master of Science in the Department of Information and Communication Engineering. The study was conducted in accordance with Code of Research Ethics[1]

Dec. 14. 2014

Approved by

Professor Ji-Woong Choi ____________ (Signature)
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(Co-Advisor)

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Performance Analysis for Full-Duplex Random Access in Distributed Networks

Dongwoo Yeom

Accepted in partial fulfillment of the requirements for the degree of Master of Science

Dec. 14. 2014

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Abstract

Abstract—In this paper, we investigate the performance analysis of full-duplex random access in distributed networks. Recently, full-duplex communication is focused on the 5G cellular and wireless networks. Full-duplex communication is able to efficiently use the bandwidth by transmitting a signal simultaneously on the same frequency band. The technical progress on the analog and digital interference cancellation makes full-duplex communication feasible in wireless networks and it can be increased in system throughput compared to the existing half-duplex system. Especially, we considered the proximity environment using the full-duplex communication such as the device-to-device communication. We can analyze the performance gain for full-duplex random access in the aspect of MAC protocol. In addition, we considered the stochastic approach for the large scale system to obtain the practical calculation. Simulation results of the ON/OFF system model show that the full-duplex random access in distributed network can improve the system throughput by up to 10 % performance gain. In addition, the results of stochastic model represented about 3-times performance improvement in the general case. We can anticipate the enhanced system performance in random access process by using the full-duplex communication in a proximity distributed system.

Keywords: Distributed network, random access, full-duplex, device-to-device

Contents

I. INTRODUCTION

The demand for wireless data traffic has increased in recent years with the growth of smart phone, wireless devices, and new applications. According to a recent report by Cisco [1], mobile data traffic is increasing 25-times by 2016. As a result, the overload of data traffic is increasing in wireless network. In order to improve the bandwidth efficiency in growth of increasing data traffic and provide the high quality of service on the wireless network, a number of researches have been progressed in all aspects of communication systems. We are focus on both techniques in terms of full-duplex (FD) and device-to-device (D2D) communication.

FD enables a wireless device to transmit and receive data simultaneously in the same frequency band. It is a promising technology for 5G communication systems as it potentially increases system capacity in the aspect of physical layer. In FD, the received signal at a device is interfered by its transmitted signal at the same device. Such the self-interference is much higher than power of the received signal. Thus, the main challenge in realizing FD is how to cancel self-interference. Various RF, analog, and digital cancellation techniques are proposed for implementation of FD communication. The mechanism for self-interference cancellation (SIC) using multiple antenna technique was proposed in [2]. However, a practical FD transceiver was implemented by adding two other techniques to the multiple antenna one to use the digital interference and RF cancellation and SIC gain of 70 dB was obtained through combination of these techniques in [3]. Recently, a single antenna for simultaneous transmission and reception is implemented for novel analog and digital cancellation techniques that cancel the self-interference to the receiver noise floor, and ensure that there is no decrease to the received signal in [4]. Besides, medium access control (MAC) protocol was proposed in [5], which is designed for centralized network. Two devices transmit their data simultaneously on the common channel. The proposed protocol utilize a busy tone on the channel to prevent the hidden terminal problem for centralized network. Furthermore, FD protocol based on carrier sense multiple access with collision guidance (CSMA/CA) was proposed for distributed networks [6].

In addition, there have been researched for D2D communication in an effort to increase efficiency of the data traffic. D2D communication enables the exchange of data traffic directly between mobile devices without base stations or the core network. D2D communication supports new usage models based on the proximity of devices such as social networking applications, peer-to-peer content sharing, and public safety communications in out of coverage. Additionally, D2D communication cooperates with each other to dramatically increase network capacity through reusing the same spectrum or using the unlicensed spectrum. D2D communication also presents additional benefits for increased area spectral efficiency, including improved cellular coverage, reduced end-to-end latency and reduced power consumption [7].

In the general case, FD is expected to increase double the capacity at the point-to-point communication and FD is capable of double the performance by the capacity region if the resource scheduling become ideal in the distributed networks [8]. Unlike the two-node point-to-point communication, the capacity of the three-node relay communication will be less than the sum of the two individual transmission rates due to inter-node interference from the source device to the destination device. However, if there are a lot of device within a cell such as the large scale network, FD is able to anticipate the more performance improvement. Especially, devices transmit a signal each other in such random access situation because FD method relatively less can be reduced. If the HD attempt to transmit a signal each other, two devices may fail to access the channel and transmission due to a collision. Therefore, we attempt performance analysis of FD in terms of the large scale network, which is able to combine with the D2D communication because FD and D2D communication are capable of increasing the system capacity for data traffic in the same cell. In addition, FD communication is suitable for low power communication system because it has to cancel the received signal from its transmission signal. D2D communication is also used to low power system in the proximity network. A lots of the existing researches have been conducted with respect to half-duplex (HD) and it have been mainly considered in the centralized network model. So that, a number of researches are required for the FD in a proximity distributed system. We assumed the D2D devices using the low-power communication and using the FD technique in proximity environment. It is anticipated of the contribution in the advantages of FD and D2D communication. Therefore, we are focusing on the FD communication in proximity distributed system such as D2D communication.

In this paper, we analyze the performance comparison of random access process for FD and HD communication in the ON/OFF system model. We assumed that there are devices operating in FD or HD mode in the communication system, which is a time-slotted system. Each device grabs the channel with a certain probability in a distributed manner without centralized controller. We define that random access process is divided by the channel grabbing and transmission process. In the existing HD method, a device transmits a signal to other devices within the capable transmission coverage after the channel grabbing process. However, FD communication can have the various communication topology according to formation of links among devices. Each topology can occur with certain probability. We consider various communication topologies in transmission process after the channel grabbing to calculate the system throughput. On the basis of this result, we conducted the system simulation through stochastic approach throughout the cell. As a result, we obtained the results that using the FD is suitable for proximity system and it is expected for the random access performance improvement of about 3-times compared to the existing HD communication in the general network model.

The remainder of this paper is organized as follows. Section II explain the basic concept for FD and D2D communication. Sections III describes the system model for a FD random access in distributed networks and stochastic approach. Sections IV analyzes the performance of the random access using the FD communication with the conditional probability. Section V contains the simulation results for random access performance. Conclusions and future works are given in Section VI.

II. BASIC CONCEPT OF RELATED WORK

A. Full-duplex communication

Wireless communication systems are generally using frequency division duplex or time division duplex to separate the devices as multiple access scheme. In frequency division duplex, all devices use different frequency bands for signal transmission to divide the received signal from transmission signal of other devices. Time division duplex systems separate each device to different time slots to support multiple devices. Unlike HD, FD communication enables a device to transmit and receive a signal simultaneously on the same frequency as shown in Figure 1. Also, it can double the capacity of wireless systems. However, the implementation of FD has some challenges although it can improve the spectral efficiency. One of the main issues of FD communication is self-interference cancellation (SIC). A device transmits and receives simultaneously in the same frequency band by own transmission signal. Self-interference usually makes that it impossible for the receiver to detect the desired signal because the power of self-interference is larger than its received signal from other devices due to propagation attenuation.

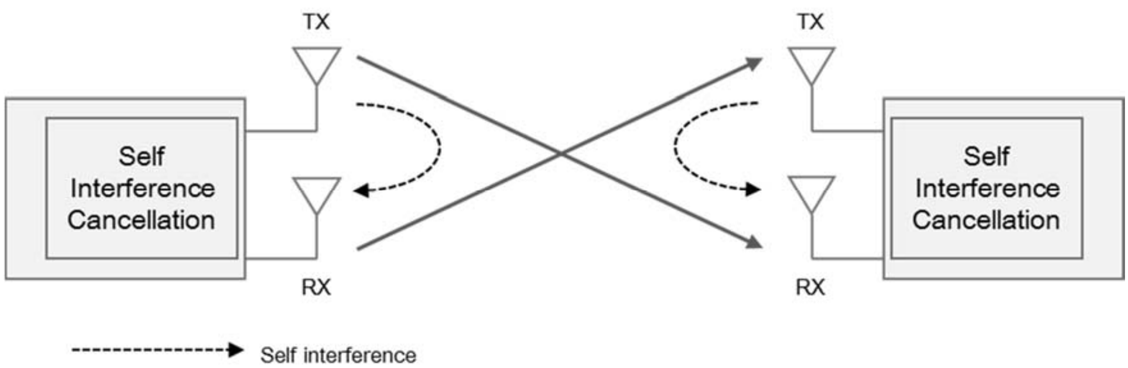

Figure 1. Self-interference cancellation in full-duplex communication

However, the progress on the analog and digital interference cancellation techniques makes FD communication feasible for 5G cellular and wireless networks. Accordingly, a lot of researches have been studied in the physical layer and RF front end design for FD system. There are some technique such as antenna cancellation, RF cancellation and digital cancellation to implement the FD.

Antenna cancellation is using two transmit and one receive antennas. In [3], the two transmit antennas are placed on distances d and $\mathrm{d} + \lambda/2$ from the receive antenna according to wavelength λ, as shown in Figure 2. Kee4ing distance of the two transmit antennas by half a wavelength causes their signals to add and cancel other signal. The receive antenna receive a weaker signal from a null position. RF interference cancellation implement self-interference cancellation in the analog domain by using a noise cancellation circuit. The transmit signal is supplied as a noise reference in the circuit and it can subtracts noise from the received signal after adjusting for phase and amplitude. Digital cancellation uses received digital samples after the analog-to-digital conversion in the receive path. The transmitted samples are stored in a local storage. The received samples are correlated with transmitted samples to determine the beginning of the transmitted signal and phase in the received samples. The transmitted samples can subtract from the received samples to cancel the transmitted signal from the received signal.

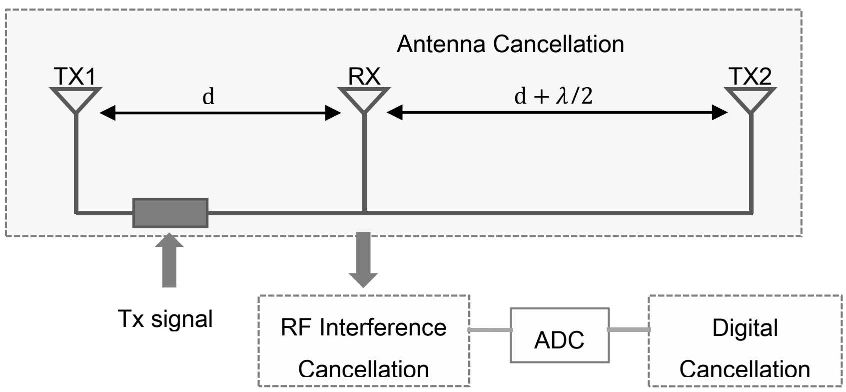

Figure 2. Block diagram of existing full-duplex design with three cancellation techniques.

Recently, a single antenna for simultaneous transmission and reception is implemented for novel analog and digital cancellation techniques that cancel the self-interference. In order to achieve FD, a radio has to completely cancel the self-interference from its own transmission to the received signal. For example, WiFi system is considered to use the average transmit power at 20dBm and the noise floor is around -90dBm. The self-interference has to be canceled by 20dBm-(-90dBm)=110dB to reduce it to the same level as the noise floor. If the self-interference is not completely canceled, any residual self-interference acts as noise to the received signal and reduces SNR because of the increasing interference. For example, if the received signal's SNR without FD is 25dB but is reduced to 5dB due to 20dB residual self-interference. It is significantly worse than using the HD link with 25dB SNR and it is better to using the FD in this case. Therefore, the amount of self-interference cancellation can influence to overall system throughput.

In the aspect of MAC protocol, the protocol of FD was designed for centralized network in [5], two nodes transmit their packet simultaneously or if one of them does not have any packet from the other node, it sends a busy-tone on the channel in order to prevent the hidden terminal problem designed for centralized networks as well, the MAC protocol is based on three methods: (1) shared random back-off, (2) header snooping and (3) virtual contention resolution. Furthermore, MAC protocol for distributed networks was proposed in [6]. The proposed protocol is based on carrier sense multiple access with collision guidance (CSMA/CA). This protocol called the CONTRA FLOW is the distributed MAC protocol that has been proposed. In this protocol, once node A captures the channel according to the CSMA/CA back-off mechanism, it starts transmitting its packet to node B and waits for the primary timer until the expiration. As soon as node B opens the header, it starts forwarding the packet to node C through an uncontended transmission. The MAC protocol design of both distributed network and infrastructure modes of WLAN is considered for new interference and contention during FD communication.

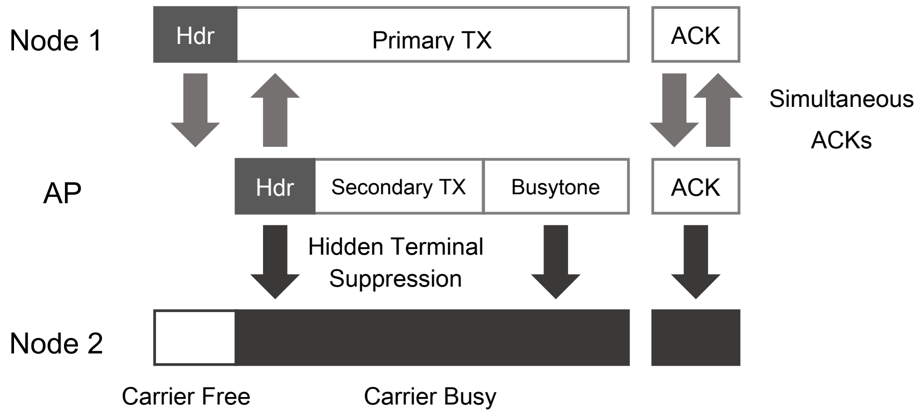

Figure 3. Full-duplex MAC protect primary and secondary transmission from hidden terminal losses.

B. Device-to-device communication

D2D is a future communication technology. D2D communication allows a device to directly communicate other devices without the base station or infrastructure. As shown in Figure 4, D2D communication has a number of advantages compared to the conventional communication system such as the cellular and centralized network. First of all, D2D communication can reduce the transmission power because it is based on the proximity service. Also, D2D communication can reduce the latency because it can communicate directly with the neighboring devices each other. The other advantage of D2D communication is offloading the cellular traffic, so that it can disperse the concentrated data traffic. Furthermore, D2D communication increases spectral efficiency by using the spatial reuse within a cell and can extend the cell coverage through the relay station in [9]. D2D communication can be divided into three part such as device discovery, link setup, and communication process and there are licensed and unlicensed band communication. In this paper, we are focusing on the distributed system such as the ad-hoc network. Among the lots of D2D communication, FlashLinQ is suitable for the distributed system operating without the central controller. We investigated the process of device discovery, paging, and communication in FlashLinQ system.

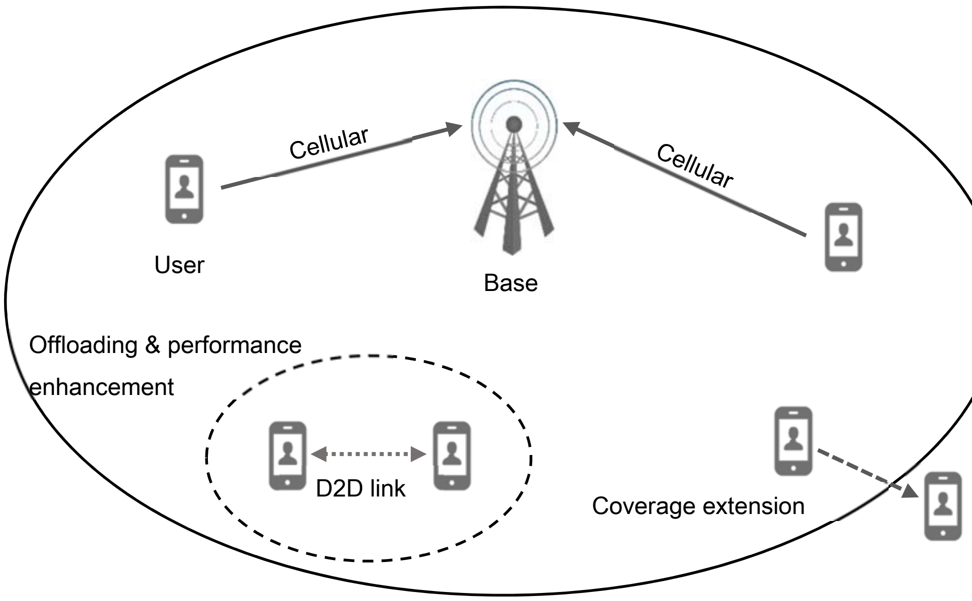

Figure 4. Device-to-device communication

2.1 Device discovery

The device discovery protocol of FlashLinQ is based on a synchronous network system and use the existing infrastructure as common external timing source such as the GPS information. FlashLinQ allocate 20ms per one second in every time slot to increase the power efficiency of discovery and paging process as shown in Figures 5. Information of each device is transmitted in the form of a single tone which is the PDRID (Peer Discovery Resource ID). In this process, all the devices periodically search the adjacent devices by participating in discovery period in the allocated time slot. Resources allocated for the entire device discovery process is divided into a large number of PDRID and each device have to choose whether to use any PDRID. A discovery slot is divided into a number of mini-slots. An 8 second interval is one discovery repetition period and consists of N_T mini-slots. In addition, the frequency band of 5MHz is divided into N_F single tone using OFDMA [10]. Thus, the discovery resource is divided into $N_T \times N_F$ PDRID. In FlashLinQ, each device select the smallest reception power of PDRID to use its own device discovery, which is referred to as a greedy selection. Devices cannot hear the information of other devices that are transmitted at different frequencies at the same timing while one device transmit the signal in their PDRID determined. In order to solve the HD problem and fading impact in certain channel, Latin square hoppling pattern that alternated transmission and reception is utilized. Device using the red color resource cannot receive the device using the blue and yellow color resource. However, it can receive the signal in the same time at different frequency if each device use the hopping pattern.

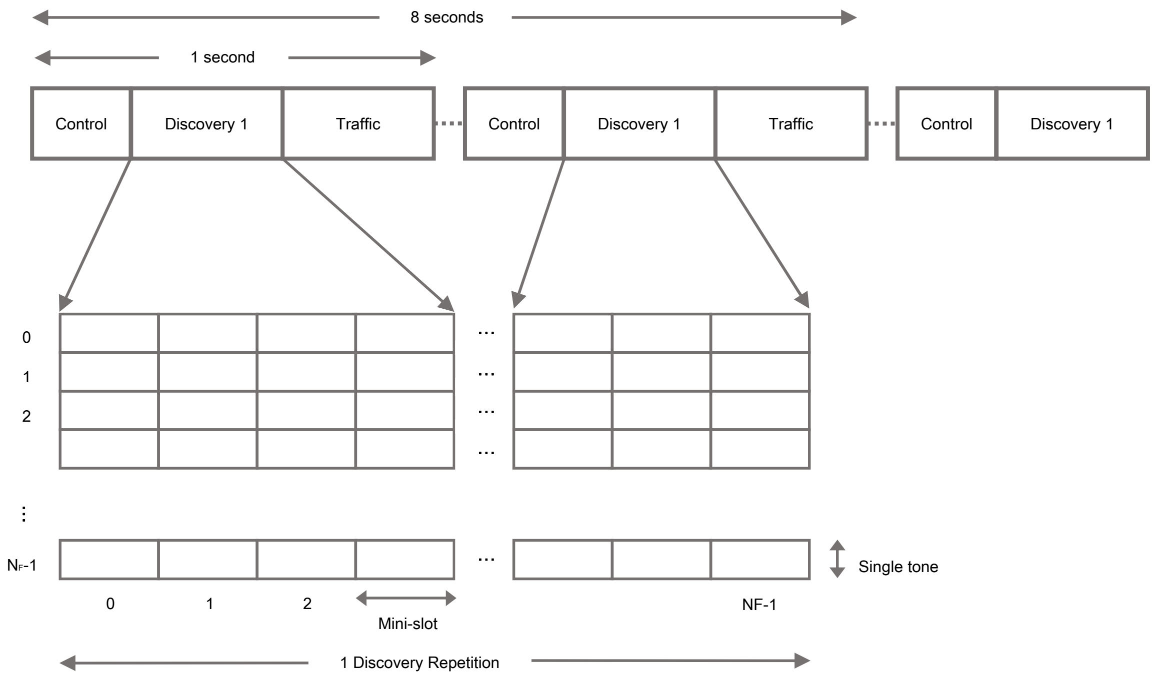

Figure 5. Device discovery in timing structure

The HD and frequency selective fading problem is solved by transmitting the signal that use Latin square pattern in frequency and time domain, which changes the resource per 8 second. As shown in Figure 5, it represent the time hopping to consider the simple case. If each device repeat 64 times for 8 seconds, all the PDRID ca be received in the vicinity of its device after 514 seconds.

2.2 Paging and data communication

Paging is the process to connect devices to transmit information when the device check the proximity through the device discovery. A transmitter request the link setup signal to receiver and response the ACK signal. The transmitter and receiver exchange user identity and other authentication information to connect a link. In this process, each link can obtain the Connection Identifier (CID) that is locally unique and is used in connection scheduling to distinguish a number of the links [11].

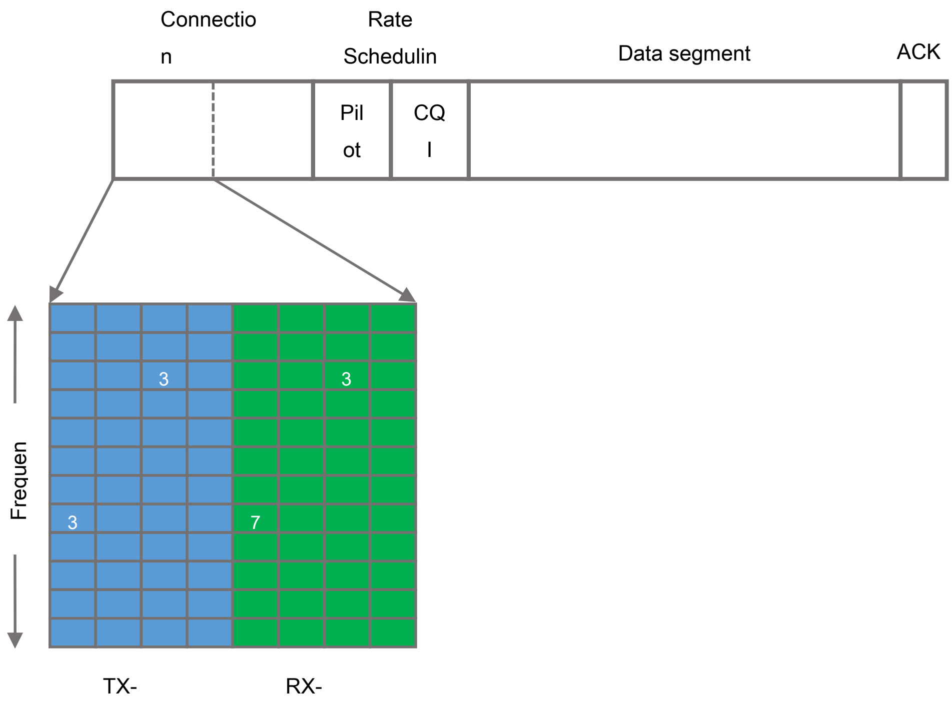

Figure 6. Connection Scheduling

Data communication procedure is the process of sending and receiving a signal process between connected devices. FlashLinQ system proposed the distinguished scheduling method based on SIR (Signal-to-Interference Ratio) for efficient spatial reuse. The connection scheduling utilize the assigned to CID in the previous step. It has the priority depending on where located. Each tone is orthogonal and priority ordering is assigning the highest priority to the top-left tone and the lowest to the bottom-right. For example, CID 7 has higher priority than CID 3 in Figure 6. These CID tones is periodically changed to maintain the fairness. If the priority of the link is given to L, the link determines whether its own communication for the link given the higher priority than L under the constraint that does not excessively interfere with the higher link. These methods is called yielding. The estimated SIR is used when each Tx-Rx pair decides whether to perform Tx-yielding or Rx-yielding. Tx-yielding is that a certain link to establish the link as it creates too much interference to other links which have higher priority than itself. On the other hand, Rx-yielding means that the link gives up the communication because of interference from other links. These methods based on SIR measurements is superior to the performance of the RTS/CTS 802.11 [11].

III. SYSTEM MODEL

A. Channel model

We assume independent and identically distributed (IID) Rayleigh fading. In addition, there is a path loss depend on a distance. When the power of transmitted signal on bandwidth is P_t, the received signal power at a distance r is

$$P_r = |h|^2 \frac{P_t}{r^\alpha}$$

where h is the Rayleigh fading and mean is 1 and α is the path loss exponent. In addition, other devices transmitting at the same time are treated as interferer except for desired link. When a device transmit a signal with power P_t, the amount of residual self-interference power kP_t, where k is the self-interference cancellation factor. As the transmit power increases, the residual self-interference increases. When the channel between two devices is an IID fast fading channel with a path loss depend on distance, the SINR of typical receiver can be expressed as

$$\mathrm{SINR} = \frac{P_t \mathrm{h} r^{-\alpha}}{\sigma^2 + I_r}$$

where

$$I_r = \sum_{i \in \Phi} P_t \mathrm{h} r_i^{-\alpha} + kP_t$$

P_t is the transmit power and r is the distance between the two devices. The interference power at the typical receiver I_r is the sum of the received power from all the interferer. The noise power is assumed to be additive and constant with value σ^2.

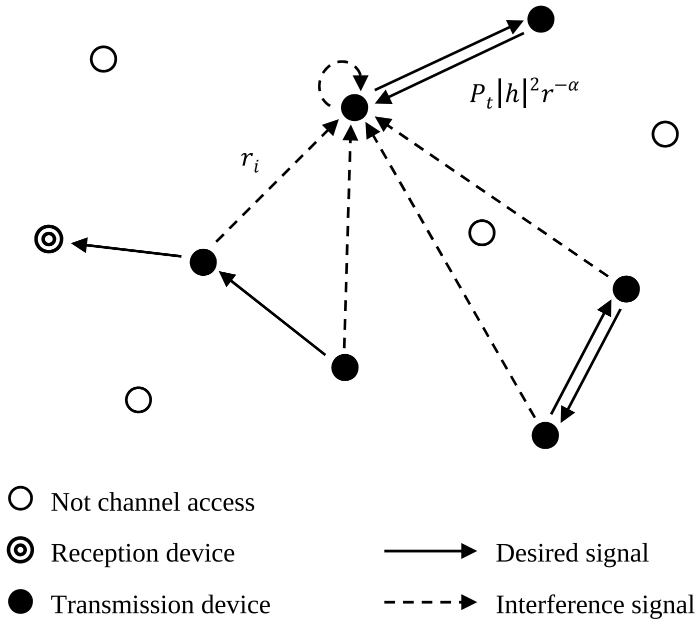

Figure 7. Channel model for random access in distributed networks

We considered the communication system applying to the channel model as shown in Figure 7. In a cell, devices are distributed randomly by the density and cell area, where each device determine channel access and transmission with the certain probability. We assume that each device select a device of the closest distance from its own device and communicate with each other because we consider the simple scenario to solve the FD random access.

B. ON/OFF system model

In this section, we consider there are *n* devices using FD or HD mode in the wireless network system. We assume each device transmits a signal to access the shared channel. The communication system is assumed to be time-slotted system with distributed random access. In a time-slot, HD mode cannot transmit and receive at the same time while FD mode can transmit and receive simultaneously on the same frequency in a time-slot. We assume all the devices have the same probability *p* to access the channel and are within the same transmission coverage not to consider external interference [12]. Random access process can be divided to channel grabbing and transmission process.

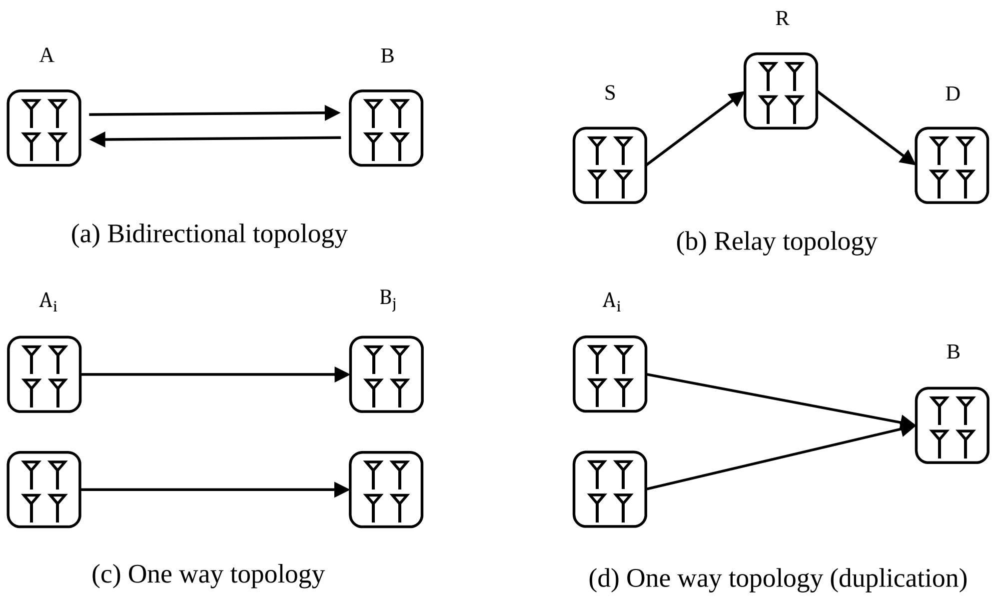

Figure 8. Transmission topologies for two active devices

A device using FD mode can transmit and receive a signal but it cannot transmit or receive two signals at the same time. Therefore, we can consider four transmission topologies according to formation of links between transmitters and receivers. If two devices are enabled to active mode after the channel grabbing, transmission scheme of active devices is divided as shown in Figure 8. In addition, we do not consider more than two active devices because the collision occurs for more than two active devices. First communication scheme (a) is bidirectional topology that is typical two-way communication. Both *A* and *B* grab the channel successfully with certain access probability *p*, which send a signal with transmission probability each other. Bidirectional topology can double the system capacity compared to HD communication. Second communication scheme (b) is relay topology, where it can send a signal through relay device *R* from source *S* to destination *D*. Both *S* and *R* successfully grab the channel with certain access probability *p*, where S sends the transmission signal to *R* and *R* sends the transmission signal to D. In relay topology, R operates in FD mode. In such a case, the link for random access is only formed between the S and R. D cannot perform link formation because there are two received signals simultaneously in a time-slot. S can interfere to D within the same transmission coverage while sending a transmission signal to R. The remaining scheme (c) is one way transmission topology that it can transmit a signal from A_i to B_j. In such a case, A_i successfully grabs the channel with certain access probability p, which sends a signal for random access to B_j. In one way transmission topology, each link cannot be formed because B_j receives simultaneously two transmission signal from A_i. A_i can interfere to the other receiver while sending a transmission signal to receiver. Duplication scheme (d) cannot perform random access in the same manner.

IV.FULL-DUPLEX RANDOM ACCESS

A. Random access probability

In this section, we analyze the performance of FD random access for the system throughputs. To calculate the performance with FD random access, we define the system throughput where each device sends a packet to other devices after channel grabbing in a time-slot and a link is successfully formed between a transmitter and receiver through transmission signal. In FD communication, two devices access the channel to send a transmission signal. We consider the conditional probability to calculate the transmission scheme probability and the successful probability of each transmission scheme is defined as p_{bi}, p_{relay}, p_{one}, and p_{dup}. In bidirectional topology (a), p_{bi} is the probability, where two devices send a transmission signal with a probability of $\frac{1}{n-1}$ each other after channel grabbing except for own device, where the remaining devices within transmission coverage do not attempt transmission for channel access. The relay topology p_{relay} sends a signal by *S* and *R* using the channel access probability *p*. After the channel grabbing, *S* and *R* have each transmission probability of $\frac{1}{n-1}$ and $\frac{n-2}{n-1}$ because R have to send a transmission signal except for *S* and *R*. The one way topology p_{one} sends a transmission signal by two devices A_i after grabbing the channel. Each device can send a signal with different transmission probability. The one device has the transmission probability of $\frac{n-2}{n-1}$ except for own transmitter and another transmitter and another device has the transmission probability of $\frac{n-3}{n-1}$ except for transmitter and one receiver. In this case, links for random access are not formed due to collision because receiver gets two transmission signals at the same time. Finally, there is duplicate topology p_{dup}. The two active devices send a transmission signal to one receiver *B* after the channel grabbing. The transmission probability of each device can be obtained to the probability of $\frac{n-2}{n-1}$. A transmission scheme is calculated by conditional probability after two devices become active mode through successful channel access. According to these transmission schemes, we can obtain the probability of FD random access when two devices become actives as follows.

$$p_{bi} = \binom{n}{2} p^2 (1-p)^{n-2} \frac{1}{(n-1)^2} \tag{1}$$

$$p_{relay} = \binom{n}{2} p^2 (1-p)^{n-2} \frac{2 \cdot (n-2)}{(n-1)^2} \tag{2}$$

$$p_{one} = \binom{n}{2} p^2 (1-p)^{n-2} \frac{(n-2) \cdot (n-3)}{(n-1)^2} \tag{3}$$

$$p_{dup} = \binom{n}{2} p^2 (1-p)^{n-2} \frac{(n-2)^2}{(n-1)^2} \tag{4}$$

Note that the sum of transmission probability of p_{bi}, p_{relay}, p_{one}, and p_{dup} is $\binom{n}{2} p^2 (1-p)^{n-2}$ since all the cases with two active transmitters have to belong to one of four cases. We have to consider both paths in the bidirectional topology (a) and one direction path in relay topology (b) to evaluate the transmission probability. Therefore, the success probability of two active devices is considered to $p_{bi} + p_{relay}$ by the successful link formation. In addition, the system throughput can be defined to (5) that is considered to HD and FD system throughput by the success probability of two active devices. We considered the normalized system throughput because we assumed that each device is filled with transmitting data packet in buffer and communicate at a certain data rate. If there are devices in the same transmission coverage, random access probability can be defined to the system throughput within the coverage according to these assumptions.

$$throughput = \binom{n}{1} p(1-p)^{n-1} + \binom{n}{2} p^2(1-p)^{n-2} \left\{ \frac{2}{(n-1)^2} + \frac{2 \cdot (n-2)}{(n-1)^2} \right\} \quad (5)$$

We assume system throughput corresponds to the number of successful transmission packet. If the devices are operated to the HD mode, the transmission probability is 1 and system throughput of the HD mode can be calculated to channel grabbing probability $\binom{n}{1} p^1(1-p)^{n-1}$ because a device can access the shared channel. In the same manner, the system throughput of FD mode can be computed using channel grabbing and transmission probability. Therefore, the sum of HD and FD throughput can be represented by the total system throughput (5). We considered the proximity environment within a transmission coverage in the previous section. In order to evaluate the system throughput, we can calculate the value of *p* in accordance with the *n*. Note that the total system throughput is a function of *p* and *n*. For *p* given *n*, it can be calculated using the partial derivative of (5).

$$\frac{\partial}{\partial p}(throughput) = -n(1-p)^{n-3}\big((n-1)p-1\big) = 0 \quad (6)$$

$$\frac{\partial}{\partial p}(FD\_gain) = -np(1-p)^{n-3}(np-2) = 0 \quad (7)$$

If each devices exist in the proximity environment and affect to interference to other devices, we can obtain the equation $9p^2 + 1 = 10p$ using (6) when there are 10 devices. It is calculated $p = \frac{1}{9}$, when $n > 2$. We are able to select about 0.1 value of the channel access probability and it can be the optimal channel access probability with respect to the 10 devices. Also, the performance gain of FD is calculated by (7) when there are 10 devices. Therefore, the performance gain is about 0.2 value of access probability. At this time, the random access performance of FD can be maximized. In addition, we can solve the maximum system throughput through the channel access probability and number of devices and we have to consider that each optimal value in accordance with the communication environment.

B. Stochastic model approach

The network model consists of a number of devices by distributed manner according to homogeneous poisson point process (PPP) Φ of density λ [13]. The distance of desired link between transmitter and receiver is r. We assume that each device communicates with the closest devices each other. All interferers are located father than the closest distance r. The typical device has a transmission coverage R that is possible coverage enduring interference from other devices. The probability density function (pdf) of r can be derived using the simple fact that the null probability of a poisson process in an area A is $\exp(-\lambda A)$.

$$\begin{aligned}\mathbb{P}[R > r] &= \mathbb{P}[\text{No interferer closer than r}] \\ &= e^{-\lambda\pi r^2}\end{aligned} \tag{7}$$

Therefore, the cdf is $\mathbb{P}[R \le r] = F_r(r) = 1 - e^{-\lambda\pi r^2}$ and the pdf can be found as

$$f_r(r) = \frac{dF_r(r)}{dr} = e^{-\lambda\pi r^2} 2\pi\lambda r \tag{8}$$

We assume that all the interferers does not exist in coverage of radious r and a typical receiver consider range R by SINR threshold.

The following theorem gives the success probability of the FD wireless network modeled by the marked PPP:

Theorem 1. The success probability for a typical devices using the bidirectional FD random access in the general distributed network model is

$$p_s = \exp\big(-\lambda p_t F(Tr^{\alpha}, \alpha, r)\big) \exp\big(-\lambda p_r F(Tr^{\alpha}, \alpha, r)\big)$$

where

$$F(\mathrm{s}, \alpha, R) = \int_0^{\infty} \left(1 - \frac{K(s, r, R, \alpha)}{1 + sr^{-\alpha}}\right) r dr$$

with $K(\mathrm{s}, \mathrm{r}, \mathrm{R}, \alpha) = \int_0^{2\pi} \left(\frac{1}{1+s(r^2+R^2+2rRcos\varphi)^{-\alpha/2}}\right) d\varphi$.

Proof: The success probability is expressed by

$$p_s = \mathrm{E}[\, P(\gamma_t > T)\, \mathrm{P}(\gamma_r > T)\, |R = r]$$

$$= \int_{r\geq 0} P(\, h > Ir^{\alpha}T) f_R(r)\, dr \int_{r\geq 0} P(\, h > Ir^{\alpha}T) f_R(r)\, dr$$

$$= \int_0^{\infty} L_{I_t}(\mu_t r^{\alpha} T)\, f_{R_r}(r) dr \int_0^{\infty} L_{I_r}(\mu_r r^{\alpha} T)\, f_{R_r}(r) dr$$

The Laplace transform $L_i(s)$ is calculated by the value *s*. the success probability can be considered by using the nearest devices distribution $f_R(r)$. The Interference I consist of the external and self-interference. It can be expressed as

$$\mathrm{I} = \sum_{i\in\Phi} (h_i R(i)^{-\alpha} + h_{s(i)} R(s(i))^{-\alpha})$$

The Laplace transform of the interference follows as

$$
\begin{aligned}
L_I(s) &= \mathrm{E}\left(\prod_{i\in\Phi} e^{-s\left(h_i R(i)^{-\alpha}+h_{s(i)} R\left(s(i)\right)^{-\alpha}\right)}\right) \\
&= \mathrm{E}\left(\prod_{i\in\Phi} \frac{1}{1+sR(i)} \frac{1}{1+sR(s(i))}\right) \\
&\triangleq \exp\left(-\lambda\pi\lambda \int_0^\infty \left(1-v(x)\right)\right) \\
&= \exp\left(-\lambda\pi\lambda \int_0^\infty \left(1-\frac{K(s,r,R,\alpha)}{1+sr^{-\alpha}}\right) r\,dr\right)
\end{aligned}
$$

where m follows from the probability generating functional of the PPP with $v(x) = \frac{1}{1+sR(i)}\frac{1}{1+sR(s(i))}$. As a result, the success probability is

$$
\begin{aligned}
p_s &= L_{I_t}(\mu_t r^\alpha T) L_{I_r}(\mu_r r^\alpha T) \\
&= \exp\left(-\lambda p_t F(Tr^\alpha, \alpha, r)\right) \exp\left(-\lambda p_r F(Tr^\alpha, \alpha, r)\right)
\end{aligned}
$$

which completes the proof.

The fact that the success probability are a product of two terms follows from the independence of the point process Φ. The success probability is not in closed-form due to the integral form of $F(Tr^\alpha, \alpha, r)$.

V. SIMULATION RESULTS

In this section, we evaluate the performance of FD random access and system simulation. We simulated the ON/OFF system model and stochastic model. The ON/OFF system model is considered to the special case of stochastic model because it is not affected to interference from other devices within the same coverage. The devices are randomly located in a 100 by 100 m to consider the proximity environment. We assumed the Rayleigh fading channel according to the random channel condition and system bandwidth is 5MHz considering the FlashLinQ system for data communication. Also, we considered the system simulation for the proximity environments using the low-power transmission to obtain the practical results. Other simulation parameters in Table 1 are described considering 3GPP cellular system [14].

Table 1. Simulation parameters

Parameter	Values
Cell range	100 * 100 [m]
System bandwidth	5 MHz
Transmit power	15 dBm
Noise power	-174 dBm/Hz
System bandwidth	5 MHz
Noise figure	9 dB
Tx antenna gain	10 dBi
Rx antenna gain	10 dBi
Implementation loss	2 dB
Channel state	5 MHz
Noise figure	Rayleigh fading channel

A. Performance evaluation in ON/OFF system model

We consider the two cases which are applied the FD and the existing HD random access in a transmission coverage. We simulated the random access results that are obtained by conditional probability according to transmission topologies. The system throughput is simulated according to channel access probability and the number of devices. Through the evaluation, we can show the performance gain that is defined as system throughput gain when the FD mode is considered in distributed random access. If a link is not formed due to collision with transmission signal by other devices, it is not considered to random access performance. We consider the successful transmission signal between transmitter and receiver.

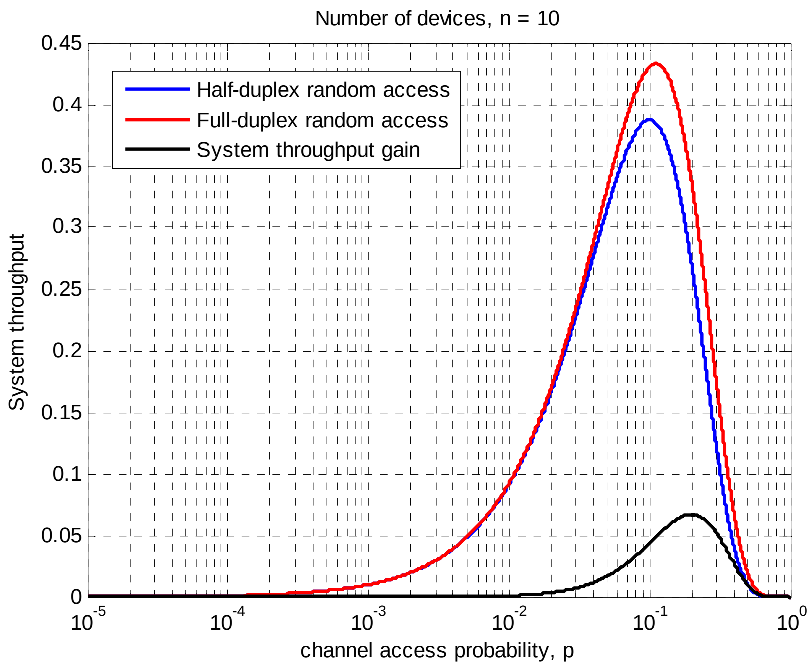

Figure 9. System throughput for number of devices and access probability in FD and HD communication

As shown in Figure 8, the system throughput of FD is larger than the HD and we know that FD throughput is the sum of the HD and system throughput gain. Using the FD in random access can be improved about 10% at the channel access probability p=0.1. As calculated in the previous section, we can figure out the FD system throughput is maximized at p=0.1. Also, this optimal channel access probability can be used to find the maximum system throughput gain according to the number of devices. When there are 10 devices, the optimal channel access probability is at 0.2. Therefore, we can find the maximum system throughput and system throughput gain to increase the spectral efficiency. However, the system throughput gain is gradually reduced in relation to increasing the number of devices because the transmission probability have the small value for a number of devices.

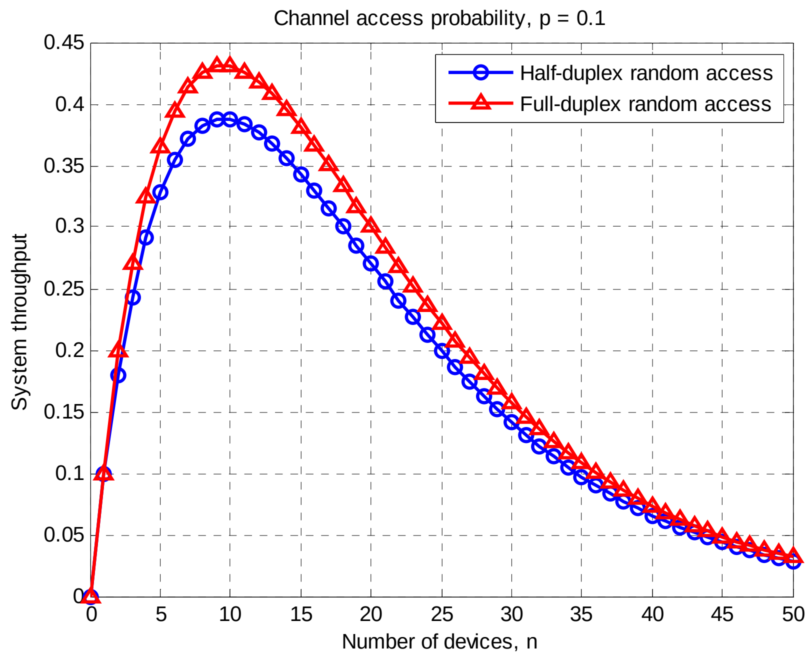

Figure 10. System throughput for the number of devices using the FD random access

Figure 10 shows the system throughput for the number of devices using the FD and HD random access. According to the optimal channel access probability, the system throughput have a different values. The channel access probability p=0.1 is used to obtain the maximum system throughput. Figure 10 shows the maximum system throughput is around the 10 devices and system throughput is decreasing according to increasing the number of devices because the each transmission schemes appear as small probability. We simulated the FD performance according to number of devices and access probability. Furthermore, we confirmed that the relationship between the number of devices and channel access probability. We can use other conditions according to the system environment to optimize the system throughput as shown in Figure 11.

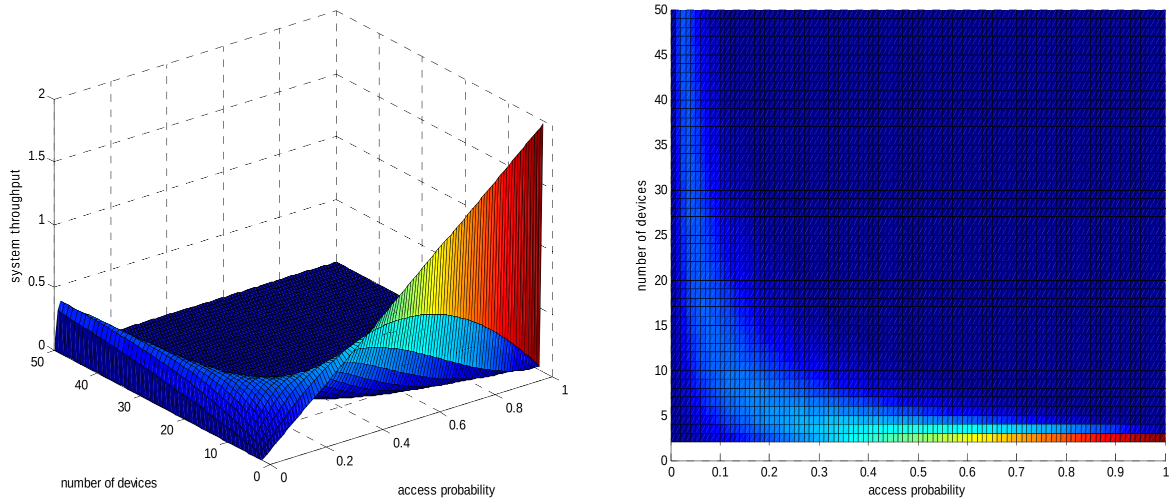

Figure 11. Relationship between number of devices and access probability

B. System capacity

In the previous section, we considered the ON/OFF system model that is applied for a special case and it is simple model that all the devices were influenced from other devices within a cell. In order to consider the practical environments, we simulated the system capacity of full- and HD random access by applying to the stochastic approach. We assumed that a typical device received a signal from the device of closest distance. All the devices except for the device of closest distance are considered to interference within the same cell. Each device access the channel with the certain probability p and send a signal by using the determined transmit power. However, if the devices transmit signals at the same time for grabbing the channel, it is considered to be collision. After the links have been successfully connected, each device calculate the SINR from the other interference and desired link except for the collision. Through these process, we simulated the SINR distribution and system capacity which is calculated by successful pairs in accordance with above SINR threshold for the overall cell.

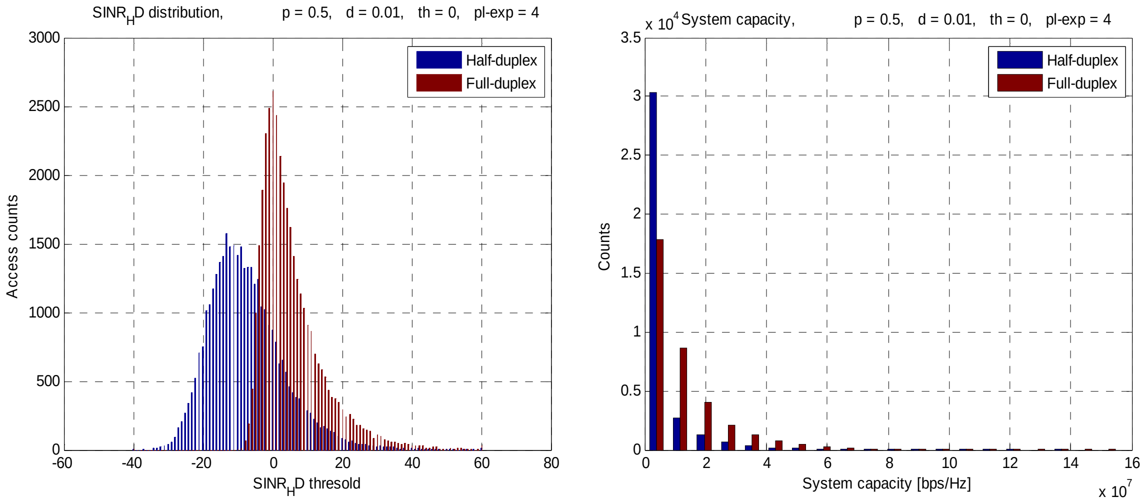

Figure 12. SINR distribution and system capacity for FD and HD

Figure 12 represented the general system model that using the FD communication in the proximity environment. We assumed that there are 50 devices in cell area of 100 x 100 m considering the access probability and collision. Each device transmit a signal using the full- and HD mode each other. In that instance, we simulated the results according to above conditions and confirmed about 3-times performance improvement than HD mode by system capacity on the right of the Figure 12.

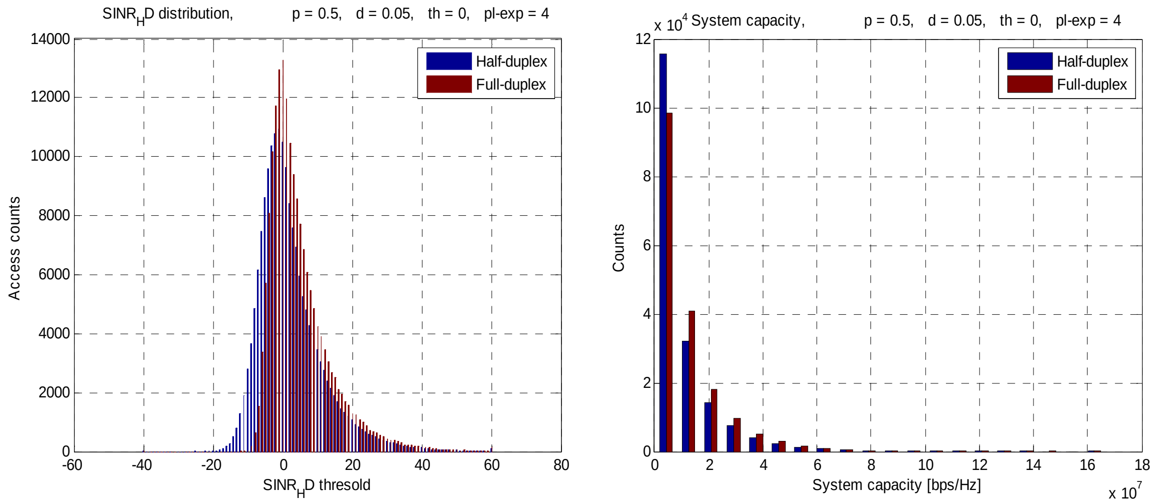

Figure 13. Performance evaluation according to density

In Figure 13, it shows the result of distribution and system capacity in terms of density. As we conducted a simulation according to the above conditions, about 500 devices are exist in the area and about 200 devices success to access the channel with the certain probability. We calculated the system capacity by successful pairs and the result represented about 1.2-times performance improvement compared the existing HD mode. Density is influence to the number of devices within the same area. So, the result for increasing density is similar with the performance of HD because the external interference is much larger than desired power. The external interference is affect to SINR calculation as dominant components.

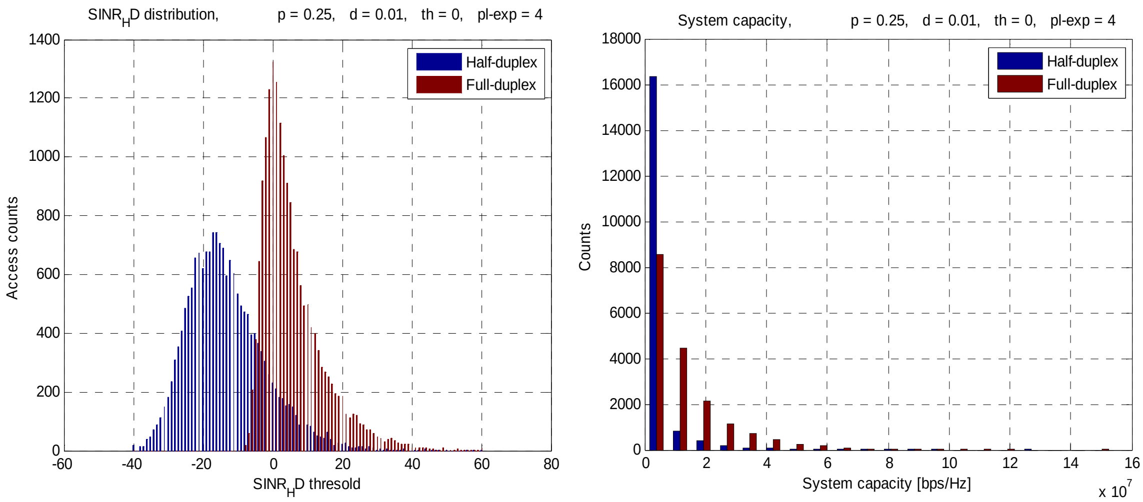

Figure 14. Performance evaluation according to access probability

Similarly, the access probability is affect to the number of devices for successful pairs. In Figure 14, the small access probability make a small number of devices to access the common channel. When we conducted a simulation according to the above terms, there are about 100 devices in the area and about 20 devices success to access the channel with the certain probability 0.25. We calculated the system capacity by above the SINR threshold and obtained the about the 5-times performance improvement. The access probability is affect to the number of devices for channel grabbing. We confirmed that the FD communication operated efficiently in the proximity environment because it is influence to the external interference through the results. FD communication have to cancel the self-interference from the own signal. However, if the number of devices increase according to the large access probability, the external interference affect dominantly on the SINR in dense environment. Through above results, FD communication is suitable in the sparse and proximity environment than dense and macro area network system.

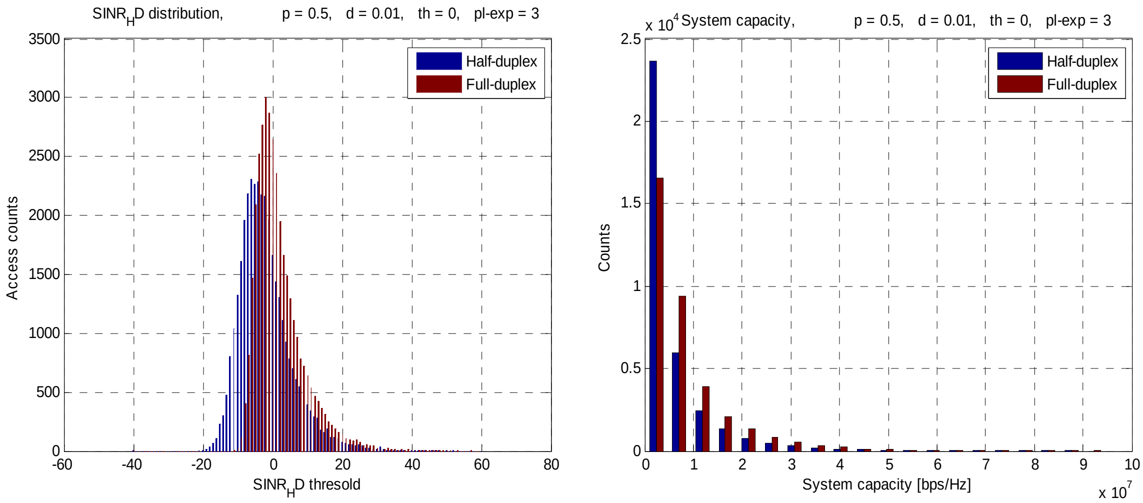

Figure 15. Performance evaluation according to path loss exponent

As shown in Figure 15, the simulation result represent the impact on the path loss exponent. Path loss exponent change the amount of loss when a device transmit a signal to other devices. We conducted a simulation in terms of the path loss exponent 3 in the same condition. The about 100 devices is exist in the same area and about 30 devices is formed to successful pairs with the certain probability. This result is compared to the Figure 12 that simulated under the same condition except for the path loss exponent. Decreasing path loss exponent mean that transmission range become the wide coverage because a loss for the distance is exponentially decreasing. Therefore, the path loss exponent determine transmission range of each device as well as change the number of devices within the coverage.

VI. CONCLUSION

This paper considers a FD random access with time-slotted system in distributed networks. We investigate the different topology according to FD transmission of active devices. It can be newly considered for FD transmission, unlike HD one. Firstly, we considered that the ON/OFF system model to obtain the performance gain of FD random access in the special case. We calculated the normalized system throughput depending on channel access probability and number of devices. Secondly, we considered the stochastic approach for the distributed proximity network and can obtain the practical result through these approach. We confirmed that the system throughput of FD random access is improved about 10% in the ON/OFF system model compared to the existing HD communication. Furthermore, we applied to the stochastic approach in order to obtain the practical results and the simulation result represented the 3-times in general proximity environment. Therefore, FD communication can be a solution to improve the bandwidth efficiency in future communication networks.

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요 약 문

전이중 통신방식을 이용한 대규모 분산 네트워크 환경에서의 Random access 성능 분석

5G 이동통신의 기술발전에 따라 고속의 데이터통신이 요구되고 대역폭을 효율적으로 사용하기 위한 기술들이 연구되고 있다. 전이중 통신방식은 같은 자원을 이용해서 동시에 송수신이 가능하도록 하는 기술이며 기존의 반이중 통신방식에 비해서 대역폭 효율을 증가시킬 수 있기 때문에 차세대 통신기술로 각광받는 기술이다. 하지만, 전이중 통신 방식은 자기간섭신호에 대한 상쇄기술이 필요하고 많은 단말들이 존재할 경우 새로운 간섭시나리오가 발생하게 된다. 본 논문에서는 전이중 통신방식에 대한 간섭시나리오를 가정하여 반이중 통신에 대한 Random access에서의 성능차이를 시뮬레이션을 통하여 보여주었다. 전이중 통신 방식에서는 양방향의 데이터 전송 이외에 중계기 역할의 전송형태가 나타날 수 있고 각각의 전송형태에 대한 확률을 이용하여 처리량을 계산했고 ON/OFF 시스템 모델로 나타내어 분석하였다. 또한, Stochastic 접근법을 이용하여 실제 환경과 비슷한 대규모 분산 네트워크 시스템에서의 성능을 분석하였고, 일반적인 모델을 가정하였을 때 전이중 통신방식은 반이중 통신방식에 비해 약 3배 정도의 성능이득이 나타나는 것을 확인하였다.

핵심어 : 전이중 통신, 분산형 네트워크, Random access, Stochastic 접근법