Performance Comparison for 2 by 2 MIMO System Using Single Leaky Coaxial Cable over WLAN Frequency Band

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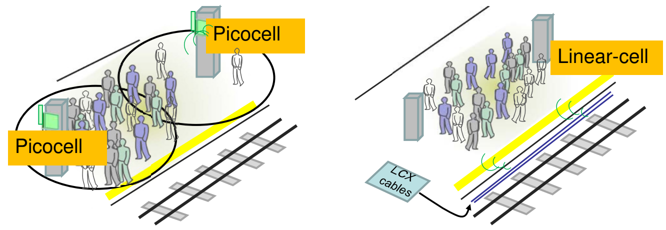
***Abstract*—In linear service areas such as a tunnel and along railways, leaky coaxial cable (LCX) is widely used as antenna for radio communication. Usually, one LCX is utilized as one antenna. Therefore it requires more than one LCX to configure an multi-input multi-output (MIMO) system. We have recently proposed a method that one single LCX can be utilized as two antennas by feeding different RF transmit signals to each end of the proposed cable. In this paper, we compare 2× 2 MIMO system performance using the proposed LCX and using conventional monopole antennas over 2.4GHz band for WLAN appliances. The results confirm that our proposed 2× 2 MIMO channel using a single LCX can realize a good channel condition and bit error ratio (BER) performance for MIMO transmission even within a highly correlated propagation condition. On the other hand, it also shows that the proposed LCX MIMO is promising technique for communications over linear-cell environments from the simulated results which considering the path loss and radiation pattern of LCX characteristics.**

I. Introduction

Multi-input multi-output (MIMO) technique is becoming a key part of the current and evolving wireless access systems such as long term evolution (LTE), WiMAX and WLAN. It is a hot study item for LTE-Advanced which can be deployed both in a large cell and in picocell or femtocell [1].

Over some long and shallow places, which is called as linear-cell environments such as tunnel, area along railway, underground shopping mall and so on, using leaky coaxial cable (LCX) as antenna for radio communication is widely used because LCX has many potential advantages. For example, its coverage is more uniform and the installation might be simpler [2]. In addition, the handover process and interference between cells can be avoided if LCXs are selected as antennas shown in Fig. 1.



(a) Picocells using conventional antennas (b) Linear-cell using LCX cables

Fig. 1. Two types of antennas applied for a linear-cell secenario.

Usually the LCX was used for lower frequency bands, but some LCXs have been designed for higher frequency such as 2.4GHz ISM band [3]. It is usually assumed that one LCX is only used as one antenna. Therefore it requires more than one LCXs to configure an MIMO system. In paper [4], two independent LCXs are utilized to configure 2×2 indoor MIMO system and some experimental studies of this type of MIMO system were reported for corridor scenario and office landscape scenario. It shows that LCXs are suited for MIMO in indoor scenarios and the observed channel MIMO quality is close to an $i.i.d.$ quality for all measurement cases. In paper [5], we have recently proposed a method that one single LCX can be utilized as two antennas. When different RF transmit signals are fed to each end of the cable, the single LCX can work as two antennas. The results confirm that the proposed 2×2 MIMO channel using a single LCX can realize a good channel condition for MIMO transmission even within a highly correlated propagation condition.

In this paper, we will further compare the 2× 2 MIMO system performance using the proposed LCX and using conventional monopole antennas over 2.4GHz band for WLAN appliances. The system performance comparison is considering the channel condition and LCX characteristic of path loss and radiation patterns to validate its advantages over the linear-cell environments.

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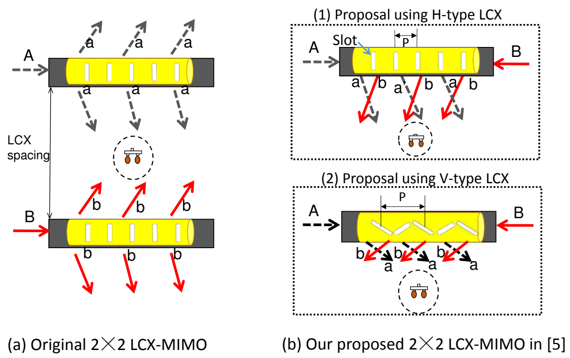


Fig. 2. The radiation characteristic of proposed LCX.

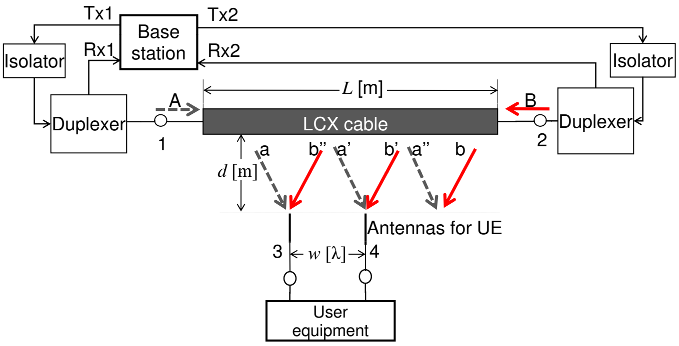


Fig. 3. 2×2 LCX-MIMO system using the proposed LCX.

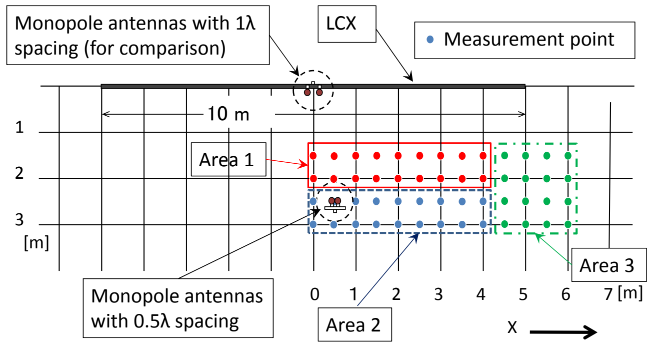


Fig. 4. Measurement points in the experiment.

This paper is organized as follows. The fundamental idea that one single LCX can be utilized as two antennas and a 2×2 MIMO system using the proposed LCX are simply described in Section II. Then the system measurement configuration and channel characteristics of the proposed 2×2 LCX-MIMO system are introduced in Section III. The simulated results of system performance using the proposed LCX and using conventional monopole antennas are shown in Section IV. The paper ends with conclusions in Section V.

II. Proposed 2×2 MIMO system using a single LCX

It is usually assumed that one LCX is only used as one antenna [6]. Therefore, as shown in Fig. 2(a), the radiation characteristic is high correlated if the input RF signal directions A and B are identical. To realize a good MIMO channel, the LCXs need to be separated with an appropriate spacing. We have proposed a novel 2×2 MIMO system that utilizes a single LCX as two antennas using different types of LCX [5]. As shown in Fig. 2(b), the radiation patterns of input RF signal have different directions. Then the signal at one receiving antenna can have low correlation with that at the other one. The results in [5] confirmed that our proposed 2×2 MIMO system using a single LCX realizes a good channel condition for MIMO transmission. On the other hand, we can adjust the direction of slot and value P to change MIMO channel with the different radiation characteristics and radiation directions such as horizontally polarized (H-type) and vertically polarized (V-type) LCXs as shown in Fig. 2(b).

Based on previous explanation, we can design a 2×2 LCX-MIMO system using a single LCX as shown in Fig. 3. Here each user equipment (UE) has two conventional antennas. In the downlink channel (base station (BS) to UE), BS transmits signals using two ends of an LCX as TX1 and Tx2 which has two different directions of RF signal propagation as A and B. Since the radiation patterns of input RF signal propagations have different directions, the signal at one receiving antenna can have low correlation with that at the other one if two receiving antennas have appropriate distance $w(\lambda)$ between each other and appropriate distance from center of the LCX. These properties are also true in the uplink channel.

III. The measurement configuration and channel characteristics of the proposed 2×2 LCX MIMO

A. System descriptions for measurements

We measured 2×2 channel matrices of the proposed LCX-MIMO and that of the conventional MIMO using monopole antennas in an anechoic chamber. Figure 4 shows the geographical setup of a measurement area and measurement points within the area. Here X axis is the direction along the LCX and Y axis is the direction from the LCX to the receiving antenna that is perpendicular from the LCX. An origin point is defined as the center of the LCX. Each receiving antenna was monopole half-wavelength monopole type. The separated distance between the UE's antennas is half the wavelength. Since there is no reflection path and channel propagation is static in an anechoic chamber, a shape of a cell that is formed by the LCX is assumed to be symmetric against X axis and Y axis. Given this assumption, the measurement area was reduced to a quarter from the entire cell area. 52 positions including 8 positions outside the end of the LCX are selected for measurement and these positions are divided into three areas marked as Area 1, Area 2 and Area 3 in Fig. 4. Area 1 represents the positions that UEs are near to the LCX; Area 2 shows the place that UEs has slightly long distance between UEs and the LCX. On the other hand, Area 3 represents the place that UEs are at/out of the edge of LCX. The configuration of the experiment is shown in Fig. 5. The LCX is laid on the edge of foaming polystyrene which is placed on the radio wave absorber. It is around 0.5m above the floor.

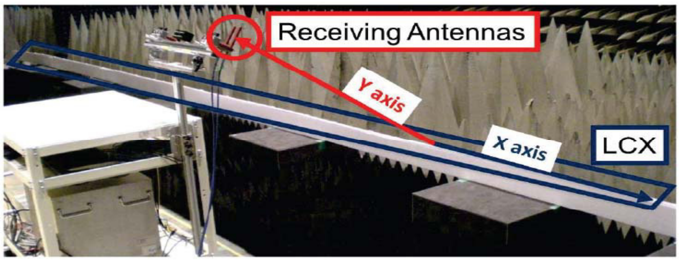


Fig. 5. A configuration of the experiment.

TABLE I
SPECIFICATIONS OF LCX

Cable type	H-type; V-type
Slot spacing P	80 mm
Coupling loss	60 dB $\pm$5 dB
Cable loss	H-type: 0.3 dB/m; V-type: 0.4 dB/m
Inner copper wire diameter	2 mm
Insulator (foamed polyethylene) diameter	5 mm
Outer sheathe thickness	1 mm
Cable diameter	7 mm

B. Metrics of channel characteristics of the proposed 2 × 2 LCX MIMO

To confirm that the proposed LCX-MIMO can realize 2 × 2 channel, we use condition number (CN) γ as a metric of MIMO system [7]. The measured 2 × 2 matrix $\mathbf{H}$ is decomposed using singular value decomposition (SVD) as $\mathbf{H} = \mathbf{U\Sigma V}^*$. Here $\mathbf{U}$ and $\mathbf{V}$ are unitary matrices. $\mathbf{\Sigma}$ =diag $\{\lambda_1, \lambda_2\}$ and λ_i is the ith eigenvalue of $\mathbf{H}$. The CN γ [dB] is computed as $\gamma = 20 \times \log_{10}(\lambda_1/\lambda_2)$. A matrix with a low CN is said to be well-conditioned matrix, it means the channel has good condition for capacity increase. Therefore, the distribution of CN can show its channel characteristics.

C. Channel characteristics of the proposed 2 × 2 LCX MIMO for WLAN usage over 2.4GHz

We choose two types of LCX, one is a H-type LCX and the other one is a V-type LCX. The major specifications of LCX are listed in Table I. The measured center frequency and bandwidth were 2.452GHz and 125MHz, respectively. 401 frequency samples were obtained in each measurement.

In this section, we will show the channel characteristics for WLAN usage over 2.4GHz with frequency band allocation as Fig. 6. The 2.4 GHz band is divided into 14 channels spaced 5 MHz apart, beginning with channel 1 which is centered on 2.412 GHz. The latter channels have additional restrictions or are unavailable for use in some regulatory domains. We

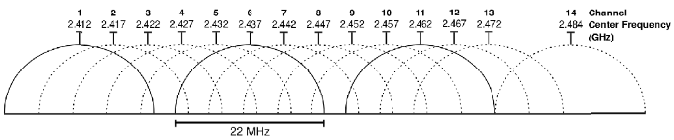
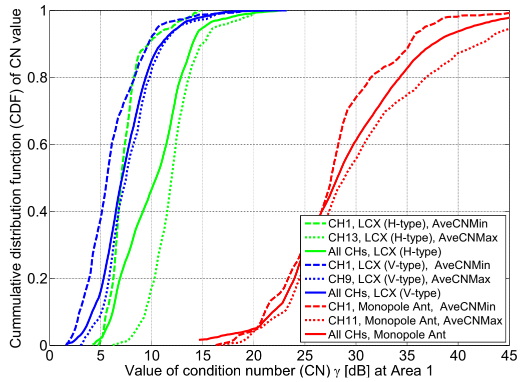
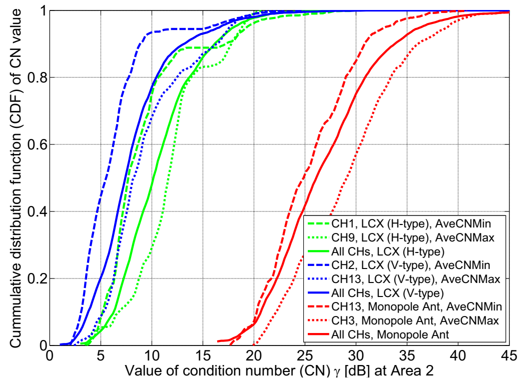


Fig. 6. The channel allocation for WLAN usage over 2.4GHz (13 channels (CHs) for usage and CH 14 is limited used or unavailable for some regulatory domains).

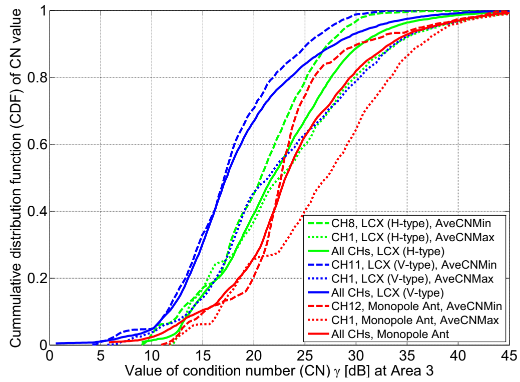
show the cumulative distribution function (CDF) of condition number value γ for each area over all 125MHz band which includes all channel bands. In addition, to show the variation between different channels, we also show the CDF of the channel which has a smallest average CN value (marked as 'AveCNMin') and the channel which has a largest average CN value (marked as 'AveCNMax') among the set from channel 1 (CH1) to CH13. The channel indexes which have the largest and smallest average CN values for different areas are given in Table II.



(a) Area 1



(b) Area 2



(b) Area 3

Fig. 7. CDF of condition number value of 2 × 2 LCX-MIMO and monopole antennas MIMO channels.

Figure 7 shows the CDF curves for each area. LCXs of both types in Area 1 show the better channel condition for

TABLE II
CHANNEL INDEXES WITH THE LARGEST AND SMALLEST AVERAGE CN VALUE FOR DIFFERENT AREAS

	Area 1				Area 2				Area 3			
	AveCNMin	$\bar{\gamma}[dB]$	AveCNMax	$\bar{\gamma}[dB]$	AveCNMin	$\bar{\gamma}[dB]$	AveCNMax	$\bar{\gamma}[dB]$	AveCNMin	$\bar{\gamma}[dB]$	AveCNMax	$\bar{\gamma}[dB]$
H-type LCX	CH1	7.45	CH13	12.1	CH1	9.14	CH9	11.71	CH8	20.5	CH1	23.41
V-type LCX	CH1	6.09	CH9	7.87	CH2	6.15	CH13	9.36	CH11	17.55	CH1	22.88
Mono-antennas	CH1	27.78	CH11	29.48	CH13	25.38	CH3	29.15	CH12	23.21	CH1	26.70

MIMO transmission than that of monopole antennas for all channels. The results show that channel matrices of conventional antennas have high correlation among each transmitting and receiving antennas due to the short distance between transmitter and receiver. Although the measurements were carried out in an anechoic chamber where no reflection path exists for both LCX cables and monopole antennas, LCXs still show better condition for MIMO transmission than the monopole antennas. In Area 2, CN value of LCXs slightly increased compared with that in Area 1. However, both types of LCX cables outperform the monopole antennas. When UE moves to the Area 3, where it is at/out of the edge of the LCX, the CN values steeply increased but were still slightly better than that of monopole antennas.

The CDF curves for the channels with the largest and smallest average CN values show that the type H-type LCX has a larger variation than that of V-type LCX over different channels at Area 1. When UE moves into Area 2 or Area 3, both types LCX and monopole antennas appear the similar variation over all frequency bands. On the other hand, the measured results also show that V-type LCX can realize better channel than the H-type LCX. This means that the direction of slot and the spacing between the slots P have large impact on the MIMO channel characteristics [6].

IV. THE SYSTEM PERFORMANCE OF THE PROPOSED 2×2 LCX MIMO

We compare the system performance of the proposed 2×2 LCX MIMO with that of the 2×2 monopole antennas MIMO in this section. The selected channels are same to the Table II which includes largest and smallest average CN values for the LCXs and monopole antennas over three areas. Every channel occupies about 20MHz band for OFDM system which has 64 subcarriers for two streams transmission. Each position of area has the same probability to be selected for performance comparison. We assume the channel estimation is perfect at receiver side. The receiver equalizes the channel effect using MMSE algorithm to demodulate two data streams. The modulation is 16QAM.

The first comparison between LCXs and monopole antennas MIMO systems is BER performance of system when the receiving power is same for all MIMO systems. For this case, the characteristics of path loss of LCXs and monopole antennas are not considered and the difference of BER performance are only related with the MIMO channel condition. The simulated results are shown in Fig. 8 for different areas. As shown in Fig. 8, the BER performance of LCX MIMO highly outperforms than that of MIMO using monopole antennas over Area 1 and Area 2. When UE moves to the Area 3, where it is at/out of the edge of the LCX, the BER performance of LCX MIMO is steeply degraded but is still slightly better than that of monopole antennas. From both Fig. 7 and Fig. 8, the simulated BER performance in Fig. 8 is highly consistent with the characteristic of CN distribution in Fig. 7. For H-type LCX in Area 2, although the average CN value in CH1 is smaller

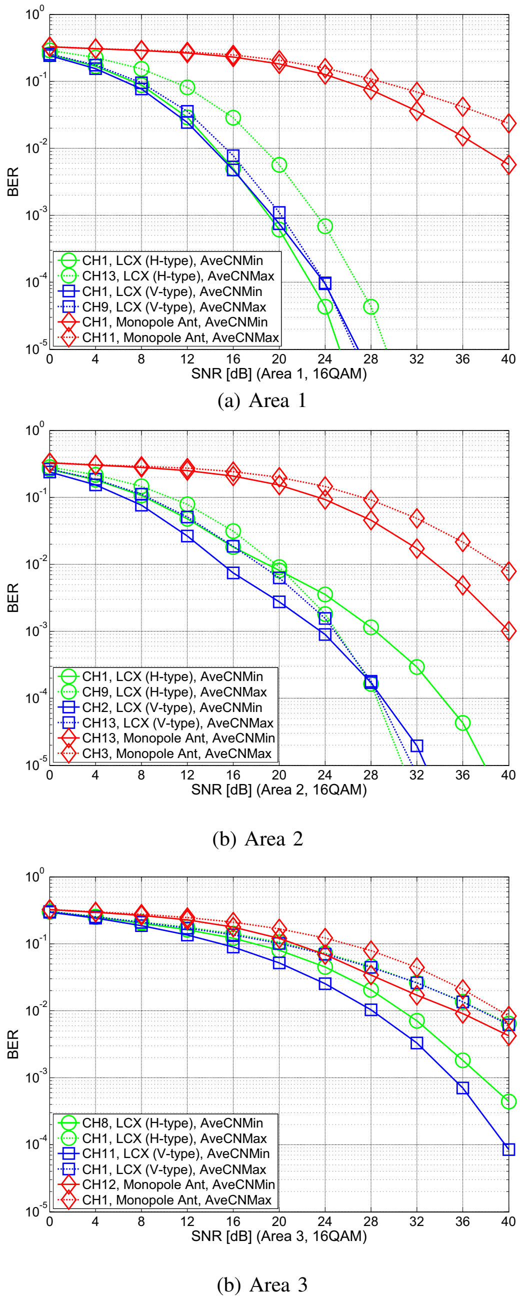
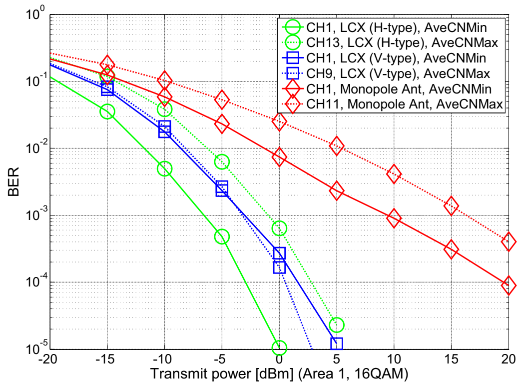
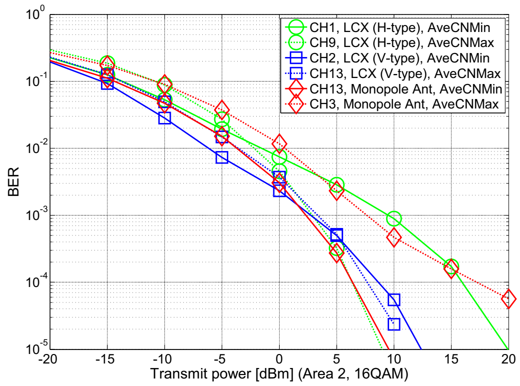


Fig. 8. BER performance comparison for MIMO system with different type antennas when the receiving power is same.

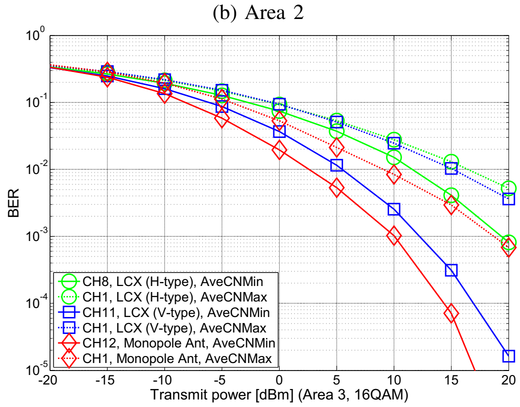
than that in CH9, BER performance in CH1 is still worse than that in CH9 if SNR value is larger than 20 [dB]. The reason is that a few measurement positions has the larger CN value in CH1 than that of all measurement positions in CH9. In such case, although the SNR is increased, the bit error cannot be reduced for these measurement positions in CH1 which causes the average BER is worse than that of in CH9.



(a) Area 1



(b) Area 2



(b) Area 3

Fig. 9. BER performance comparison for MIMO system with different type antennas when the transmit power is same.

The second comparison between LCXs and monopole antennas MIMO systems is BER performance of system when the transmit power is same for MIMO systems. For this case, the MIMO channel condition and characteristic of path loss of LCXs and monopole antennas are both considered for system comparison. The simulated results are shown in Fig. 9 for different areas. As shown in Fig. 9, the BER performance of LCX MIMO outperforms than that of MIMO using all monopole antennas over Area 1. However, when UE moves to the Area 2, the BER performance of the MIMO using monopole antennas is highly improved and almost identical to that of LCX MIMO. When UE moves to the Area 3, the BER performance of LCX MIMO is steeply degraded and the MIMO using monopole antennas appear better performance. The reason is that the pass loss of LCX is larger than that of monopole antennas. Therefore, the BER performance of LCX MIMO is better in Area 1, where the distance between receiver and transmitter is smaller, than that of Area 2. However, in Area 1, due to LOS component, the matrix of MIMO channel using monopole antennas is a highly correlated one. The BER performance is degraded even the path loss is a small value. When UE moves to Area 2, the correlation of MIMO channel using monopole antennas is reduced and the BER performance is improved.

Both comparisons show that the proposed 2×2 MIMO system using a single LCX realizes a good channel condition for MIMO transmission. The LCX characteristics of path loss and radiation patterns support that it can be utilized for communications over some long and shallow places as linear-cell environments where the distance between receiver and transmitter is small.

V. Conclusions

In this paper, we have compared 2×2 MIMO system performance using proposed LCX and using conventional monopole antennas over 2.4GHz band for WLAN appliances. The system performance comparison is considering both the channel condition of LCX and the LCX characteristic of path loss and radiation patterns to validate the its advantages over the linear-cell environments. The results confirmed that our proposed 2×2 MIMO channel using a single LCX can realize a good channel condition and BER performance for MIMO transmission even within a highly correlated propagation condition. On the other hand, it also shows that the proposed LCX MIMO is promising technique for communications over linear-cell environments.

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