Comparison of Isotropic and 3D Beamforming LTE Systems Using Simulation

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Abstract. 4G LTE system uses an isotropic antenna to transmit radio wave power uniformly in all directions. In contrast, 3D beamforming is a 5G technology that directs the radio wave beam power towards those user equipment intended for communication thereby increasing SINR and decreasing the BER experienced at the User Equipment (UE). This paper compares the performance of an isotropic LTE system with a 3D beamforming system by quantifying the average Signal Noise Ratio (SNR) and Bit Error Rate (BER) received by all UEs in its coverage area.

Keywords: 3D beamforming · 5G · LTE · Simulation · BER

1 Introduction

There are several technologies for 5G designers that promise improved system performance and the 3D MIMO beamforming is one of the key technologies for 5G system [1]. This paper develops a methodology for estimating the parameters of the beamforming weighting function of a 3D antenna array and shows how the 3D MIMO beamforming is applied in the LTE system. This idea is based on "Study on 3D channel model for LTE, 3GPP TR 36.873" [2]. The advantage of directing a 3D beamforming to a group of users is that the very high bandwidth channel can be shared between a large number of users using time and frequency division multiplexing in Orthogonal Frequency Division Multiplexing (OFDM) without significantly changing the beamforming direction thereby simplifying the control at the BS and simplifying the synchronization of the user terminals with the transmitted channel. The cost is that the user terminals experience a range of BER qualities.

This paper simulates a 3D beamforming system to quantify the range of BER qualities that are obtained when directing a beamforming towards a group of user terminals. The simulation results show better performance than the original LTE system. The energy from each antenna is focused so the received signal strength at the user terminal is strong, which influence the signal quality. For example, if mobile phone may not receive a signal when the user is in the building or is far from the base station then a weighting function is necessary, which can focus the total energy from antenna array so that the signal can be sent further and the signal quality is enhanced at the user equipment. The simulations show that mean BER for the population of user terminals is improved compared to an isotropic LTE system.

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Section 2 establishes the channel model and the weight matrix for directing the 3D beamforming towards the UEs. Section 3 explains how the 3D beamforming technology is applied to LTE system. Section 4 explains the parameters in the simulation. Section 5 presents and analyses the results from the simulation. Section 6 provides a conclusion for the whole paper.

2 3D Beamforming Channel Model

2.1 Calculating Channel Coefficients

The channel coefficients have been obtained from "3GPP TR 36.873" [2]. In next paragraphs, the H is the channel coefficient. Figure 1 shows the two kinds of path in the channel model. One of them is Non-line of sight (NLOS) and other is Line-of-sight (LOS).

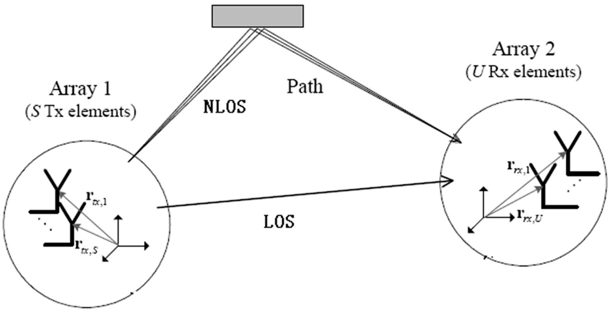

Fig. 1. The single channel model. In figure, the NLOS is Non-line of sight and the LOS is line of sight. The lines are the path.

There are two kinds of channel coefficients. The channel coefficient for the NLOS is [2]:

$$
\begin{aligned}
H_{u,s,n}(t) = \sqrt{P_n/M} \sum_{m=1}^{M} & \begin{bmatrix} F_{rx,u,\theta}\left(\theta_{n,m,ZOA}, \varphi_{n,m,AOA}\right) \\ F_{rx,u,\varphi}\left(\theta_{n,m,ZOA}, \varphi_{n,m,AOA}\right) \end{bmatrix}^T \\
& \begin{bmatrix} exp\left(j\Phi_{n,m}^{\theta\theta}\right) & \sqrt{\kappa_{n,m}^{-1}} exp\left(j\Phi_{n,m}^{\theta\varphi}\right) \\ \sqrt{\kappa_{n,m}^{-1}} exp\left(j\Phi_{n,m}^{\varphi\theta}\right) & exp\left(j\Phi_{n,m}^{\varphi\varphi}\right) \end{bmatrix} \\
& \begin{bmatrix} F_{tx,s,\theta}\left(\theta_{n,m,ZOD}, \varphi_{n,m,AOD}\right) \\ F_{tx,s,\varphi}\left(\theta_{n,m,ZOD}, \varphi_{n,m,AOD}\right) \end{bmatrix} \\
& \cdot \; exp\left(j2\pi 2_0^{-1}\left(\hat{r}_{rx,n,m}^T . \bar{d}_{rx,u}\right)\right) \\
& \cdot \; exp\left(j2\pi 2_0^{-1}\left(\hat{r}_{tx,n,m}^T . \bar{d}_{tx,s}\right)\right) \cdot exp\left(j2\pi 2_{n,m} t\right)
\end{aligned} \tag{1}
$$

The channel coefficient for the LOS is [2]:

$$H_{u,s,n}(t) = \sqrt{\frac{1}{K_R+1}} H'_{u,s,n}(t) + \delta(n-1)\sqrt{\frac{K_R}{K_R+1}} \begin{bmatrix} F_{rx,u,\theta}(\theta_{LOS,ZOA}, \varphi_{LOS,AOA}) \\ F_{rx,u,\varphi}(\theta_{LOS,ZOA}, \varphi_{LOS,AOA}) \end{bmatrix}^T \begin{bmatrix} exp(j\Phi_{LOS}) & 0 \\ 0 & -exp(j\Phi_{LOS}) \end{bmatrix} \begin{bmatrix} F_{tx,s,\theta}(\theta_{LOS,ZOD}, \varphi_{LOS,AOD}) \\ F_{tx,s,\varphi}(\theta_{LOS,ZOD}, \varphi_{LOS,AOD}) \end{bmatrix} . exp\left(j2\pi 2_0^{-1}\left(\hat{r}^T_{rx,LOS} \cdot \bar{d}_{rx,u}\right)\right) . exp\left(j2\pi 2_0^{-1}\left(\hat{r}^T_{tx,LOS} \cdot \bar{d}_{tx,s}\right)\right) \quad (2)$$

Since the propagation paths over which the signal is transmitted is not deterministic, the probability of existence for each path must be set. The calculation for probability of the LOS is defined in Ref. [2]. This probability defines how the power is distributed for different paths. If the power is less than −25 dB, then this path is ignored.

2.2 Calculating the Weight Matrix

A BS (base station) is equipped with antenna array that consists of MN antenna elements which is shown in Fig. 2.

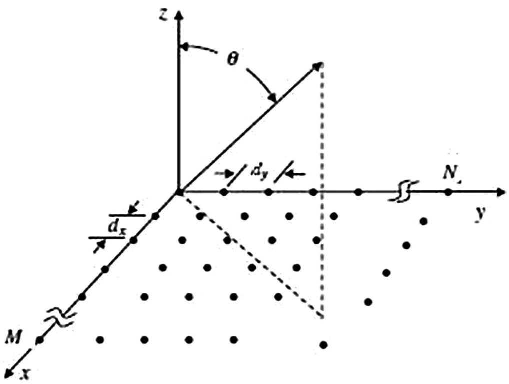

Fig. 2. There are N elements in the y-direction and M elements in the x-direction.

In order to represent the different location of antenna elements, the direction matrix D is introduced.

$$D = \begin{bmatrix} d_{11} & d_{12} & \cdots & d_{1M} \\ d_{21} & d_{22} & \cdots & d_{2M} \\ \vdots & \vdots & \cdots & \vdots \\ d_{N1} & d_{N2} & \cdots & d_{NM} \end{bmatrix} \qquad d_{ik} = e^{j[(i-1)\beta_x + (k-1)\beta_y]}$$

where $\beta_x = -\frac{2\pi}{\lambda} d_x \sin\theta_0 \cos\phi_0 = -\pi \sin\theta_0 \cos\phi_0$, $\beta_y = -\frac{2\pi}{\lambda} d_V \sin\theta_0 \sin\phi_0 = -\pi \sin\theta_0 \sin\phi_0$.

2.3 Calculating the Weight Vector

In order to allow the desired signal to be received without modification and reject the undesired interfering signals, we let AF = 1 in the desired direction and AF = 0 in the undesired interfering direction. That is in the desired direction, we hope $AF_x = 1$ is for a_m and $AF_y = 1$ is for bn. in the undesired direction, we hope $AF_x = 0$ and $AF_y = 0$.

(1) Calculating the weight vector in x-direction $\begin{bmatrix} a_1 & a_2 & \cdots & a_M \end{bmatrix}^T$

$$\begin{aligned} AF_x &= \sum_{m=1}^{M} a_m e^{j(m-1)(kd_x sin\theta in\theta\varphi + \beta_x)} \\ &= \begin{bmatrix} 1 & e^{j(kd_x sin\theta in\theta\varphi + \beta_x)} & \ldots & e^{j(m-1)(kd_x sin\theta in\theta\varphi + \beta_x)} \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \\ \cdots \\ a_M \end{bmatrix} \end{aligned} \quad (3)$$

In our paper, there are four beams, so we can let the one desired direction is $\theta = \theta_0$ and $\varphi = \varphi_0$; three undesired direction are respectively:

$$\theta = \theta_1 \text{ and } \varphi = \varphi_1$$
$$\theta = \theta_2 \text{ and } \varphi = \varphi_2$$
$$\theta = \theta_3 \text{ and } \varphi = \varphi_3$$

In the desired direction, from (3), we have:

$$AF_x = \begin{bmatrix} 1 & e^{j(kd_x sin\theta_0 cos\varphi_0 + \beta_x)} & \ldots & e^{j(m-1)(kd_x sin\theta_0 cos\varphi_0 + \beta_x)} \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \\ \cdots \\ a_M \end{bmatrix} = 1 \quad (4)$$

In undesired direction, from (3), we have

$$AF_x = \begin{bmatrix} 1 & e^{j(kd_x sin\theta_0 cos\varphi_0 + \beta_x)} & \ldots & e^{j(m-1)(kd_x sin\theta_0 cos\varphi_0 + \beta_x)} \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \\ \ldots \\ a_M \end{bmatrix} = 0 \quad (5)$$

$$AF_x = \begin{bmatrix} 1 & e^{j(kd_x sin\theta_0 cos\varphi_0 + \beta_x)} & \ldots & e^{j(m-1)(kd_x sin\theta_0 cos\varphi_0 + \beta_x)} \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \\ \ldots \\ a_M \end{bmatrix} = 0 \quad (6)$$

$$AF_x = \begin{bmatrix} 1 & e^{j(kd_x sin\theta_0 cos\varphi_0 + \beta_x)} & \ldots & e^{j(m-1)(kd_x sin\theta_0 cos\varphi_0 + \beta_x)} \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \\ \ldots \\ a_M \end{bmatrix} = 0 \quad (7)$$

According to (4)–(7), we obtain

$$\begin{bmatrix} 1 & e^{j(kd_x sin\theta_0 cos\varphi_0 + \beta_x)} & \ldots & e^{j(m-1)(kd_x sin\theta_0 cos\varphi_0 + \beta_x)} \\ 1 & e^{j(kd_x sin\theta_1 cos\varphi_1 + \beta_x)} & \ldots. & e^{j(m-1)(kd_x sin\theta_1 cos\varphi_1 + \beta_x)} \\ 1 & e^{j(kd_x sin\theta_2 cos\varphi_2 + \beta_x)} & \ldots. & e^{j(m-1)(kd_x sin\theta_2 cos\varphi_2 + \beta_x)} \\ 1 & e^{j(kd_x sin\theta_3 cos\varphi_3 + \beta_x)} & \ldots. & e^{j(m-1)(kd_x sin\theta_3 cos\varphi_3 + \beta_x)} \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \\ \ldots \\ a_M \end{bmatrix} = \begin{bmatrix} 1 \\ 0 \\ 0 \\ 0 \end{bmatrix} \quad (8)$$

To obtain the weight vector $[\mathrm{a}_1 \quad \mathrm{a}_2 \quad \cdots \quad \mathrm{a}_{\mathrm{M}}]^T$, we solve the equation

$$\mathrm{AX} = \mathrm{b} \quad (9)$$

where

$$A = \begin{bmatrix} 1 & e^{j(kd_x \sin\theta_0 \cos\varphi_0 + \beta_x)} & \ldots & e^{j(m-1)(kd_x \sin\theta_0 \cos\varphi_0 + \beta_x)} \\ 1 & e^{j(kd_x \sin\theta_1 \cos\varphi_1 + \beta_x)} & \ldots & e^{j(m-1)(kd_x \sin\theta_1 \cos\varphi_1 + \beta_x)} \\ 1 & e^{j(kd_x \sin\theta_2 \cos\varphi_2 + \beta_x)} & \ldots & e^{j(m-1)(kd_x \sin\theta_2 \cos\varphi_2 + \beta_x)} \\ 1 & e^{j(kd_x \sin\theta_3 \cos\varphi_3 + \beta_x)} & \ldots & e^{j(m-1)(kd_x \sin\theta_3 \cos\varphi_3 + \beta_x)} \end{bmatrix} \quad b^T = [1 \quad 0 \quad \ldots \quad 0]$$

Since $X = pinv(A) * b$ is the solution of (9), we obtain

$$[\mathrm{a}_1 \quad \mathrm{a}_2 \quad \cdots \quad \mathrm{a}_{\mathrm{M}}]^T = pinv(A) * b$$

Repeat these steps to calculate the weight vector in Y-direction; and then combining those two weight vectors and direction matrix D obtained in Sect. 2.2 to determine the weight for transmitted signal.

3 Applying the 3D Beamforming in LTE System

The simulation of LTE system is according to "PDSCH Throughput Conformance Test for Single Antenna (TM1), Transmit Diversity (TM2), Open Loop (TM3) and Closed Loop (TM4/6) Spatial Multiplexing" from the LTE System Toolbox in Matlab 2016a. The downlink reference measurement channel configuration is from "3GPPTS 36.101, Table A.3.1.1-1" [3] as Table 1 shown.

Table 1. Overview of DL reference measurement channels.

Reference channels	Reference channels
R.0 (Port0, 1 RB, 16QAM, CellRefP = 1, R = 1/2)	R.26 (Port5, 50 RB, 16QAM, CellRefP = 1, R = 1/2)
R.1 (Port0, 1 RB, 16QAM, CellRefP = 1, R = 1/2)	R.27 (Port5, 50 RB, 64QAM, CellRefP = 1, R = 3/4)
R.2 (Port0, 50 RB, QPSK, CellRefP = 1, R = 1/3)	R.28 (Port5, 1 RB, 16QAM, CellRefP = 1, R = 1/2)
R.3 (Port0, 50 RB, 16QAM, CellRefP = 1, R = 1/2)	R.10 (TxDiversity|SpatialMux, 50 RB, QPSK, CellRefP = 2, R = 1/3)
R.4 (Port0, 6 RB, QPSK, CellRefP = 1, R = 1/3)	R.11 (TxDiversity|SpatialMux|CDD, 50 RB, 16QAM, CellRefP = 2, R = 1/2)
R.5 (Port0, 15 RB, 64QAM, CellRefP = 1, R = 3/4)	R.12 (TxDiversity, 6 RB, QPSK, CellRefP = 4, R = 1/3)
R.6 (Port0, 25 RB, 64QAM, CellRefP = 1, R = 3/4)	R.13 (SpatialMux, 50 RB, QPSK, CellRefP = 4, R = 1/3)
R.7 (Port0, 50 RB, 64QAM, CellRefP = 1, R = 3/4)	R.14 (SpatialMux|CDD, 50 RB, 16QAM, CellRefP = 4, R = 1/2)
R.8 (Port0, 75 RB, 64QAM, CellRefP = 1, R = 3/4)	R.25 (Port5, 50 RB, QPSK, CellRefP = 1, R = 1/3)
R.9 (Port0, 100 RB, 64QAM, CellRefP = 1, R = 3/4)	R.11-45RB (CDD, 45 RB, 16QAM, CellRefP = 2, R = 1/2)

The simulation program chooses the R.0 and R.5 to simulate because the LTE system is a SISO system and the environment channel is Rayleigh fading channel model. The modulation method is 16-QAM, which is R.0 and it is 64-QAM, which is R.5.

4 The Simulation of Program

The simulation program is about the LTE system using the 3D beamforming technology. The simulation results compare with the LTE system. The GUI Fig. 3 is:

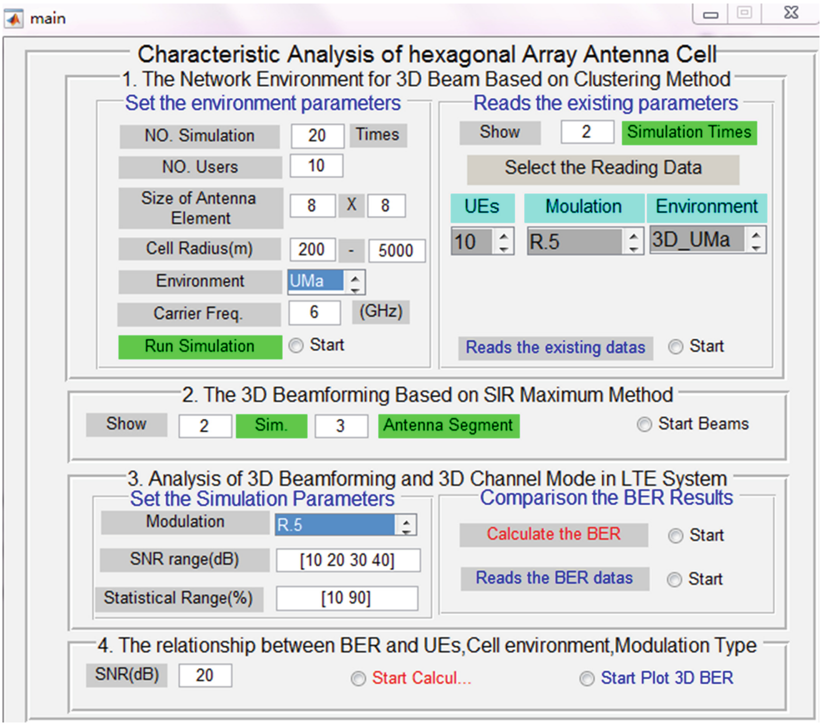

Fig. 3. The first box is the options of parameters for the simulation. The second box is the options for showing which beam. The third box is the options for calculating the BER. The last box is choice of the SNR for BER in 3D LTE system.

The operating time takes more than 8 h so there is the option about reading the data from operated in before.

5 Analysis Results

Choose a 10 users random distribution in one cell. The each beam is sent from 8 × 8 antenna array. The environment is UMa and the modulation is 64-QAM (R.5). More parameters for simulation are shown in Table 2. Figures 4 and 5 show the constellation diagram of received symbols for one user when the modulation methods are 64-QAM in LTE system and 3D LTE system respectively.

Table 2. The setting of simulation parameters.

Options	Parameters
NO. Simulation	20 times
NO. Users	10
Size of antenna element	8 × 8
The min distance of cell	200 m
The max distance of cell	5000 m
Environment	UMa
Modulation	R.5
SNR range (dB)	[10 20 30 40]

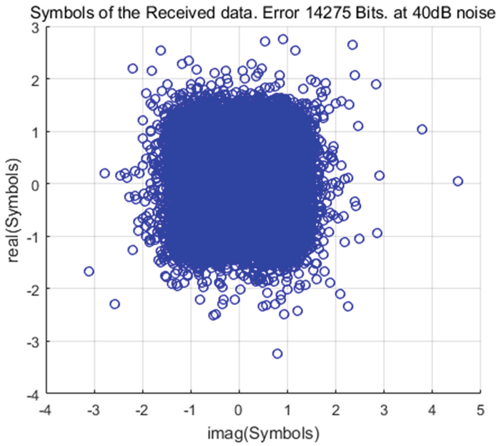

Fig. 4. The constellation diagram of received symbols in 64-QAM LTE system

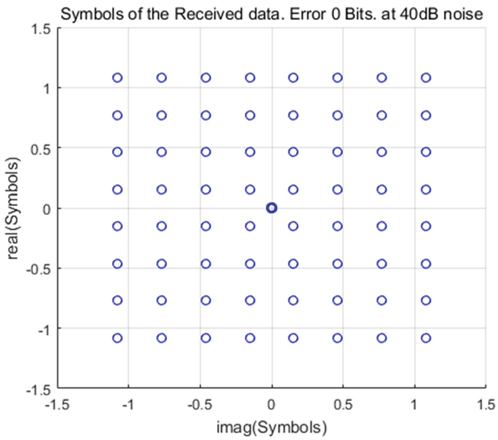

Fig. 5. The constellation diagram of received symbols in 64-QAM 3D beam LTE system

Comparing Figs. 4 and 5, the received symbols in 64-QAM 3D beam LTE are better than the 64-QAM LTE system.

The Fig. 6 shows the comparison with BER between LTE system and 3D beam LTE system in 64-QAM.

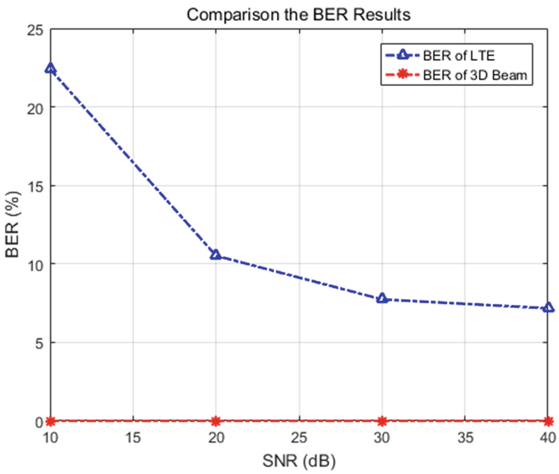

Fig. 6. The red line is the BER of 3D beam LTE system and the blue is the BER of LTE system. (Color figure online)

In Fig. 6, if the modulation method is 64-QAM, the BER of 3D LTE system is closed zero, but the BER of SISO LTE system is more than 7%, which is larger than the BER of 3D LTE system too much.

Therefore, the 3D LTE system has a better BER than the SISO LTE system when the modulation method is 64-QAM. Then we test the effect from the number of users and different environments on the BER in 3D LTE system when the SNR is 20 dB. The results are shown in Fig. 7 and the Table 3 explains the significance of all parameters in Fig. 7.

Table 3. The setting of simulation parameters.

Name	Explain
BER (%)	The median values of all BER
UEs	The number of users
UMiR.5	The modulation methods is 64-QAM in UMi
UMiR.0	The modulation methods is 16-QAM in UMi
UMaR.5	The modulation methods is 64-QAM in UMa
UMaR.0	The modulation methods is 16-QAM in UMa

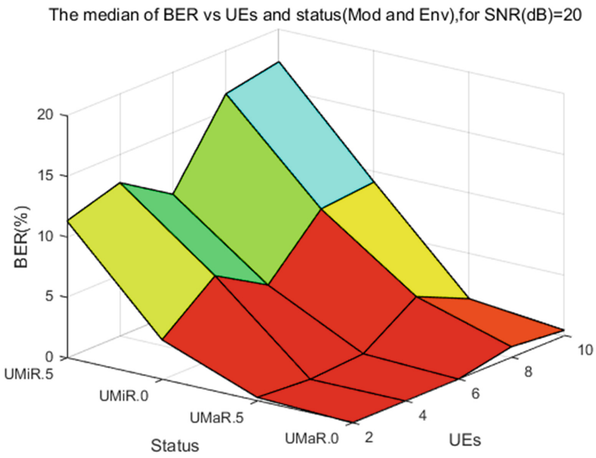

Fig. 7. The BER for different environments in 20 dB when the number of users are 2, 4, 6, 8 or 10.

6 Conclusion

This paper first develops a methodology for estimating the parameters of the beamforming weighting function of a 3D antenna array for directing the beam towards one user terminal. The weighting makes the direction of energy from each antenna to be focused on one direction. Moreover, the weighting makes the SINR between every two beams to be smaller. The simulation of 3D beamforming applied to the LTE system show that mean BER for the population of user terminals is improved compared to an isotropic LTE system transmission but this is at the cost of the variability of the BERs experienced by a small number of user terminals.

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