Sensor Integration to LTE/LTE-A Network through MC-CDMA and Relaying

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***Abstract*—In this paper, we propose a method to connect a group of wireless sensors to LTE/LTE-A system by using the cellular users as mobile relays, with the basic principle of maintaining the normal traffic between the cellular users and eNodeB during the sensor data collection. The cellular spectrum is re-used on sensor-to-mobile relay link without employing additional frequency resources. Multi-carrier CDMA methods are suspected to be utilized by sensor nodes, where data of each sensor is spread to the whole re-used cellular spectrum to create a low data rate transmission. In order to avoid additional complex receiver on cellular terminals, the simple amplify-and-forward relaying scheme is used at mobile relays. Since eNodeB can observe the cellular traffic components in the re-used spectrum exactly, it has the capability of canceling them in the received overlapped signals, and detecting the sensor data by using advanced multi-user detection methods. Finally, the end-to-end outage probability is analyzed and a closed-form approximation is derived. The numerical results show that the approximate closed-form equation is significant and that the proposed scheme can be used to collect sensor data in LTE/LTE-A networks.**

I. Introduction

Generally WSN are distributed and serve several objectives by processing massive amounts of observed data. Hence, the data collection is an important issue in WSN. Sensor gateways are mainly used to collect WSN information and forward to the backhaul. In an obstructed environment, a reliable communication range should be guaranteed by utilizing fixed repeaters/gateways or the sensors integrated with more advanced routing capabilities. However, the drawbacks are the increased cost and complexity. Another solution is to use mobile terminals to perform as sensor gateways, although it requires additional devices to be integrated and is not always desired.

Nowadays, the cellular terminals, including mobile phones and laptops, etc., have good coverage in most cases, and therefore using them for WSN to access backhaul is an attractive solution. The approaches for cellular mobile terminals to enable sensor originated data collection and processing via Bluetooth, were investigated in [1,2]. Since a cellular terminal with Bluetooth module can be re-used as a gateway, it eliminates the need of carrying additional devices. However, the data communication via Bluetooth always requires authorization between the transceiver and receiver, which is impractical and inconvenient for the cellular user (UE).

In the next generation mobile communication networks such as Long Term Evolution/Long Term Evolution-Advanced (LTE/LTE-A) systems, relay techniques including decode-and-forward (DF), amplify-and-forward (AF) and estimate-and-forward (EF) methods are expected to be applied [3-5], even in mobile terminals. Hence, it is possible to exploit normal cellular mobile terminals as relays to collect and forward WSN information, where the cellular spectrum is to be re-used on sensor-to-relay link. The idea of re-using licensed bands by cognitive radio sensors was studied in [6-8], where WSN is able to switch the working spectrum between ISM band and licensed band, for example, TV band. Thus, it provides a possible solution for re-using the cellular spectrum by WSN.

In this article, we propose a novel scheme to connect a group of wireless sensors and LTE/LTE-A system by re-using the cellular terminals as mobile relays. Since the sensor nodes are energy-aware devices, their transmitters can employ multi-carrier-CDMA (MC-CDMA) methods [10] to spread each data symbol onto the whole re-used spectrum, where a low data rate transmission to mobile relay is created. Without the need to use additional frequency resources, the cellular spectrum is re-used on sensor-to-relay link, while keeping the normal traffic between the cellular users and eNodeB during the sensor data collection. The AF relaying scheme is assumed to be employed by the mobile relay, and it does not need additional complex multi-user detection receiver for the cellular terminals. In addition, since eNodeB has the capability of canceling the cellular component exactly in overlapped signals, it can detect the signals from different sensors successfully by using advanced multi-user detection methods. We analyze the end-to-end outage probability and derive a closed-form approximation. From the numerical results, the approximate closed-form equations are shown to be useful and may also reveal that the proposed scheme can be used to collect sensor data in LTE/LTE-A networks.

The rest of the paper is organized as follows. In Section II, we describe the system model and propose a method to connect WSN and cellular networks. In Section III, the end-to-end outage probability is analyzed. The numerical results and conclusions are given in Section IV and V respectively.

II. System Model and Proposed Sensor Data Collection Method

In this paper, we consider a system model with multiple sensor nodes (SN) as sources, one mobile user (UE) as a relay and one eNodeB (eNB) as the destination. The signals from

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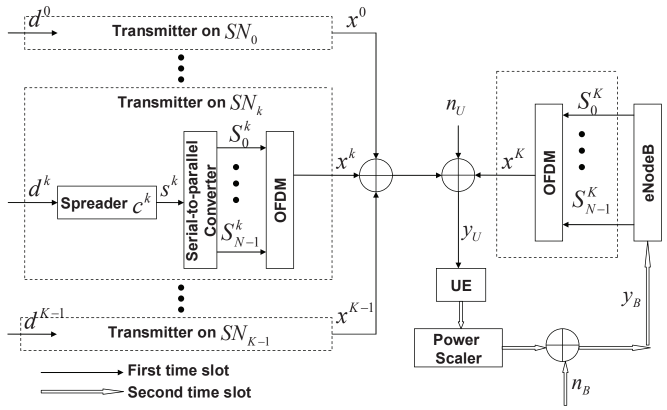

Fig. 1. Simplified block diagram of system model and MC-CDMA transmitter on SN

eNB to UE are based on OFDM, while a SN sends information to UE via MC-CDMA links. In each resource block (RB), the number of sub-carriers is assumed to be identical as N and the transmit power on each sub-carrier from the same transmitter is constant. All the links among the nodes on each RB are supposed to be quasi-static flat fading channels with Rayleigh distribution.

We assume that the sensor data collection and relaying signals are implemented through orthogonal channels. For simplicity, we will concentrate on a time division multiplex, for which the SNs and UE transmit in separate time slots. The proposed scheme can be extended in a straightforward manner to other orthogonal multiplex techniques, e.g., frequency division multiplex where UE only forwards the sensor data on every second frame.

First, the SNs sense a UE that has moved into their coverage, and send request for connection. After pairing possibly between multiple sensors and one UE, UE carries out the spectrum sensing to select M adjacent RBs that have signals with the lowest average power and are not used by the target UEs, where M is an integer. Since the channels in each RB are supposed to be independent, we assume $M = 1$ in this paper and the results can be easily extended to the case of multiple RBs. Thus, the selected spectrum, denoted by f_U including N sub-carriers, is then allocated to the paired SNs. Meanwhile, UE applies for the usage of f_U from the cellular network. The location and spectrum sensing operated by SNs and UE respectively are always assumed to be successful. There are K active SNs, denoted by SN_k, to pair with a single UE at a given time, where k may take on the values $0, \cdots, K-1$.

Then, as shown in Fig.1, the K SNs transmit MC-CDMA signals with different spreading codes via f_U simultaneously, while eNB sends OFDM signals on the same band. The orthogonal MC-CDMA signal is generated by a serial concatenation of classical DS-CDMA and OFDM operation [9]. For example, let d^k be a data symbol assigned to SN_k, whose symbol duration is T_d^S. In the transmitter, d^k is first spread to the whole frequency spectrum with a user specified spreading code sequence $\mathbf{c}^k = (c_0^k, c_1^k, \cdots, c_{N-1}^k)$ of length N, where N is the same as the number of re-used sub-carriers and represents the processing gain. The higher the processing gain obtained, the lower the power density is needed to transmit information. The chip duration is $T_c^S = \frac{T_d^S}{N}$ and the data sequence obtained after spreading is given by:

$$\mathbf{s}^k = d^k \mathbf{c}^k = \{S_0^k, S_1^k, \cdots, S_{N-1}^k\} \tag{1}$$

After passing through a serial-to-parallel converter, $\mathbf{s}^k$ is modulated in parallel onto N sub-carriers to generate an OFDM symbol x_k, whose duration is

$$T_{sym}^S = NT_c^S = T_d^S \tag{2}$$

On the first time slot, x^k is transmitted loading only one data symbol. Meanwhile, let $\mathbf{s}^K = \{S_0^K, S_1^K, \cdots, S_{N-1}^K\}$ be an original data symbol sequence with duration T_d^B per data at eNB that is seen as the $K-$th transmitter. After serial-to-parallel converting and modulating $\mathbf{s}^K$ onto N sub-carriers on f_U, x^K is generated as an OFDM symbol with duration $T_s^B = NT_d^B$ to be sent on the first time slot as well. It is obvious that one OFDM symbol from eNB loads N data symbols. In order to superimpose x_k and x_K with each other, we have to design T_d^S to satisfy the relationship of data rate as

$$\frac{1}{T_d^S} = \frac{1}{T_{sym}^S} = \frac{1}{T_{sym}^B} = \frac{1}{NT_d^B} \tag{3}$$

Thus, the low data rate transmissions from SNs to UE are created and the overlapped signals received by UE on the first time slot are given by

$$y_U = \sum_{k=0}^{K} \sqrt{P^k} h_U^k x^k + n_U \tag{4}$$

where P^k is a value of power including the transmit power and the pass-loss effect from the $k-$th transmitter to UE. It is assumed that P^k is constant as P_{av}, when k takes on the values $0, \cdots, K-1$. Although the path-loss effect from different SN to UE should be distinct, the transmit power can be selected according to accurate power control [10]. h_U^k is a channel coefficient on $k-$th transmitter-to-UE link with Rayleigh distribution and varies block by block. The additive noise component $n_U(t)$ is zero-mean Gaussian with variance σ_U^2. In our system model, since the sources are SNs and cannot be far away from UE, the near-far effect from different SN can be ignored, but the delay from eNB should be taken into account at the same time. However, in this paper, the whole system is assumed to be fully synchronized, and the problem of asynchronous system will be studied in the future.

When AF relaying scheme is utilized, the UE only needs to scale the transmit power and forward the processed signals to eNB, on the following possible time slot when f_U is allocated to UE. The received signals at eNB are written as:

$$y_B = \beta y_U h_{UB} + n_{UB} \tag{5}$$

where β is a power scaling factor as $\beta=\sqrt{\frac{P_U}{E\{|y_U|^2\}}}=\sqrt{\frac{P_U}{\sum_{k=0}^{K}P^k|h_U^k|^2+\sigma_U^2}}$ and P_U is a value including the transmit power of UE and the path-loss effect to eNB. h_{UB} is a channel coefficient on UE-to-eNB link with Rayleigh distribution. n_{UB} is a zero-mean additive Gaussian noise with variance σ_{UB}^2.

Because the component x^K is sent and hence known exactly by eNB, it can be canceled as:

$$z_B=y_B-\beta h_U^K h_{UB}x^K=\beta\sum_{k=0}^{K-1}\sqrt{P^k}h_U^k h_{UB}x^k+\widetilde{n} \tag{6}$$

where $\widetilde{n}=\beta n_U h_{UB}+n_{UB}$ is the equivalent noise, whose variance is

$$\sigma_E^2=|\beta h_{UB}|^2\sigma_U^2+\sigma_{UB}^2 \tag{7}$$

Consequently, the problem has been converted to decoding overlapped MC-CDMA signals and the advanced multi-user detection techniques can be applied, for instance, maximum likelihood detection, block liner equalization and interference cancelation [9,11,12]. Nevertheless, in order to decode the signals successfully, the power scaling factor β and the channel coefficient $h_U^k, k=0,\cdots,K$ should be observed by eNB via additional control channels.

III. End-to-end outage probability analysis

In this section, the end-to-end outage probability from SN_k to eNB is analyzed, where $k=0,\cdots,K-1$, and a closed-form expression is given.

First, we assume that $\overline{\gamma}_{UB}=\frac{P_{UB}}{\sigma_{UB}^2}$, $\gamma_{av}=\frac{P_{av}}{\sigma_U^2}$ and $\overline{\gamma}_{BU}=\frac{P^K}{\sigma_U^2}$ are the average received SNR on the links of UE-eNB, any SN-UE and eNB-UE respectively. According to (6) and (7), the instantaneous received SNR of MC-CDMA signals from SN_k to eNB is given by:

$$\gamma^k=\frac{P_{av}|\beta h_{UB}h_U^k|^2}{\sigma_E^2}=\frac{\gamma_{UB}\gamma_U^k}{\gamma_{UB}+\gamma_U^k+C} \tag{8}$$

where $\gamma_{UB}=\overline{\gamma}_{UB}|h_{UB}|^2$, $\gamma_U^k=\gamma_{av}|h_U^k|^2$, $C=\gamma_{BU}+\gamma_U'+1$, $\gamma_{BU}=\overline{\gamma}_{BU}|h_U^K|^2$ and $\gamma_U'=\gamma_{av}\sum_{i=0,i\neq k}^{K-1}|h_U^i|^2$. C is fully independent on γ_{UB} and γ_U^k. Let γ_{th} be a received SNR threshold from any SN to eNB. In order to achieve a target performance, the higher the processing gain of MC-CDMA operation obtained, the smaller γ_{th} required. Thus, the end-to-end outage probability from SN_k to eNB can be written as:

$$Pr(\gamma^k\leq\gamma_{th})=\int_1^\infty Pr(\frac{\gamma_{UB}\gamma_U^k}{\gamma_{UB}+\gamma_U^k+c}\leq\gamma_{th}|c)f_C(c)dc \tag{9}$$

where $Pr(\frac{\gamma_{UB}\gamma_U^k}{\gamma_{UB}+\gamma_U^k+c}\leq\gamma_{th}|c)$ as a conditional probability given c can be expressed as [13]

$$Pr(\frac{\gamma_{UB}\gamma_U^k}{\gamma_{UB}+\gamma_U^k+c}\leq\gamma_{th}|c)=1-\omega e^{-\varsigma}K_1(\omega) \tag{10}$$

where $\omega=2\sqrt{\frac{\gamma_{th}(\gamma_{th}+c)}{\overline{\gamma}_{UB}\gamma_{av}}}$, $\varsigma=\gamma_{th}\frac{\overline{\gamma}_{UB}+\gamma_{av}}{\overline{\gamma}_{UB}\gamma_{av}}$ and $K_1(\cdot)$ is a first-order modified Bessel function of the second kind. Let $f_{\gamma_{BU}}(x)$ and $f_{\gamma_U'}(x)$ be the probability density function (PDF) of variable γ_{BU} and γ_U', then $f_C(c)$, the PDF of variable C is written as

$$f_C(c)=\begin{cases} f_{\gamma_{BU}}(c-1), K=1 \\ \int_0^{c-1}f_{\gamma_{BU}}(c-z-1)f_{\gamma_U'}(z)dz, K\geq 2\end{cases} \tag{11}$$

Since the channel attenuation factor of each link is statistically independent with Rayleigh distribution, it is known that $\gamma_{BU}\sim EXP(\overline{\gamma}_{BU}^{-1})$ and $\gamma_U^k\sim EXP(\gamma_{av}^{-1})$, where $EXP(\alpha)$ represents an exponential distribution with factor α. Thus, we have

$$f_{\gamma_{BU}}(z)=\frac{1}{\overline{\gamma}_{BU}}e^{-\frac{z}{\overline{\gamma}_{BU}}} \tag{12}$$

The PDF of γ_U' follows a chi-squared distribution with $2(K–1)$ degrees of freedom given by

$$f_{\gamma_U'}(z)=\frac{z^{K-2}e^{-\frac{z}{\gamma_{av}}}}{(K-2)!\gamma_{av}^{K-1}} \tag{13}$$

We substitute (12) and (13) into (11) and integrate according to [14, eq.(3.351.4)], to have:

$$f_C(c)=\begin{cases}\frac{1}{\overline{\gamma}_{BU}}e^{-\frac{c-1}{\overline{\gamma}_{BU}}},\ K=1\\ \frac{1}{\overline{\gamma}_{BU}\gamma_{av}^{K-1}}e^{-\frac{c-1}{\overline{\gamma}_{BU}}}\rho^{K-1}(1-e^{-\frac{c-1}{\rho}}\sum_{k=0}^{K-2}\frac{(c-1)^k}{k!\rho^k}),\ K\geq 2\end{cases} \tag{14}$$

where $\rho=\frac{\overline{\gamma}_{BU}-\gamma_{av}}{\overline{\gamma}_{BU}\gamma_{av}}$. We proceed by substituting (10) and(14) into (9), which yields

$$Pr(\gamma^k\leq\gamma_{th})=\begin{cases}\frac{1}{\overline{\gamma}_{BU}}\Delta_1,\ K=1\\ \frac{\rho^{K-1}}{\overline{\gamma}_{BU}\gamma_{av}^{K-1}}(\Delta_1-\sum_{k=0}^{K-2}\frac{1}{k!\rho^k}\Delta_2), K\geq 2\end{cases} \tag{15}$$

where $\Delta_1=\int_1^\infty(1-\omega e^{-\varsigma}K_1(\omega))e^{-\frac{c-1}{\overline{\gamma}_{BU}}}dc$ and $\Delta_2=\int_1^\infty(1-\omega e^{-\varsigma}K_1(\omega))e^{-\frac{c-1}{\overline{\gamma}_{BU}}}e^{-\frac{c-1}{\rho}}(c-1)^k dc$. Let ω replace c to be integrated in Δ_1, we have

$$\begin{aligned}\Delta_1&=D_0\int_u^\infty(1-\omega e^{-\varsigma}K_1(\omega))\omega e^{-v\omega^2}d\omega\\&=D_0(\frac{1}{2v}e^{-vu^2}-e^{-\varsigma}(\Delta_3-\Delta 4))\end{aligned} \tag{16}$$

where $D_0=\frac{\overline{\gamma}_{UB}\gamma_{av}}{2\gamma_{th}}e^{-\frac{\gamma_{th}+1}{\overline{\gamma}_{BU}}}$, $u=2\sqrt{\frac{\gamma_{th}(\gamma_{th}+1)}{\overline{\gamma}_{UB}\gamma_{av}}}$, $v=\frac{\overline{\gamma}_{UB}\gamma_{av}}{4\gamma_{th}\overline{\gamma}_{BU}}$, $\Delta_3=\int_0^\infty\omega^2e^{-v\omega^2}K_1(\omega)d\omega$ and $\Delta_4=\int_0^\infty\omega^2e^{-v\omega^2}K_1(\omega)d\omega$. According to [14, eq.(6.631.3)], Δ_3 is derived as $\Delta_3=\frac{1}{2v}e^{\frac{1}{8v}}W_{-1,\frac{1}{2}}(\frac{1}{4v})$, where $W_{-1,\frac{1}{2}}(\cdot)$ represents a Whittaker function [19]. In terms of the characteristics of modified Bessel function of the second kind in [16], when $\alpha>0$, we can make an approximation for small arguments $0<x\ll\sqrt{\alpha+1}$ as $K_\alpha(x)\approx\frac{\Gamma(2)}{2}(\frac{2}{x})^\alpha$. When $\alpha=1$, we have $K_1(x)\approx\frac{1}{x}$ for $0<x\ll\sqrt{2}$. By assuming that u is an argument small enough, we get an approximation $\Delta_4\approx\int_0^\infty\omega^2e^{-v\omega^2}\frac{1}{\omega}d\omega=\frac{1}{2v}(e^{-vu^2}-1)$. We substitute the results of Δ_3 and Δ_4 into (16) and obtain

$$\Delta_1\approx\frac{D_0}{2v}(e^{-vu^2}-e^{-\varsigma}(e^{\frac{1}{8v}}W_{-1,\frac{1}{2}}(\frac{1}{4v})+e^{-vu^2}-1)) \tag{17}$$

Similarly, let ω replace c to be integrated, Δ_2 is rewritten as

$$\Delta_2 = D_1 \int_u^{\infty} (1-\omega e^{-\varsigma} K_1(\omega))\omega e^{-\frac{\varphi\omega^2}{\gamma_{av}}} (\omega^2 - \frac{\gamma_{th}+1}{\varphi})^k d\omega \tag{18}$$

where $D_1 = 2\varphi^{k+1} e^{\frac{\gamma_{th}+1}{\gamma_{BU}}}$ and $\varphi = \frac{\overline{\gamma}_{UB}\gamma_{av}}{4\gamma_{th}}$. According to [14, eq.(1.111)], eq.(18) is extended to

$$\begin{aligned}\Delta_2 =& D_1 \sum_{i=0}^{k} \binom{k}{i} (-\frac{\gamma_{th}+1}{\varphi})^{k-i} \int_u^{\infty} (1-\omega e^{-\varsigma} K_1(\omega))\omega e^{-\frac{\varphi\omega^2}{\gamma_{av}}} \omega^{2i} d\omega \\ =& D_1 \sum_{i=0}^{k} \binom{k}{i} (-\frac{\gamma_{th}+1}{\varphi})^{k-i} (\Delta_5 - e^{-\varsigma}(\Delta_6 - \Delta_7))\end{aligned} \tag{19}$$

where $\Delta_5 = \int_u^{\infty} \omega^{2i+1} e^{-\frac{\varphi\omega^2}{\gamma_{av}}} d\omega$, $\Delta_6 = \int_0^{\infty} \omega^{2i+2} e^{-\frac{\varphi\omega^2}{\gamma_{av}}} K_1(\omega) d\omega$ and $\Delta_7 = \int_0^{u} \omega^{2i+2} e^{-\frac{\varphi\omega^2}{\gamma_{av}}} K_1(\omega) d\omega$. By applying the identity [14, eq.(3.351.2)], Δ_5 can be solved as $\Delta_5 = \frac{1}{2}(\frac{\gamma_{av}}{\varphi})^{i+1}\Gamma(i+1, \frac{\varphi u^2}{\gamma_{av}})$, where $\Gamma(\cdot,\cdot)$ is an upper incomplete Gamma function. According to [14, eq.(6.631.3)], we have $\Delta_6 = \frac{1}{2}(\frac{\gamma_{av}}{\varphi})^{i+1}\Gamma(i+2)\Gamma(i+1) e^{\frac{\gamma_{av}}{8\varphi}} W_{-(1+i),\frac{1}{2}}(\frac{\gamma_{av}}{4\varphi})$, where $\Gamma(\cdot)$ represents a normal Gamma function. Using the abovementioned approximation of Bessel function, Δ_7 can be approximated as $\Delta_7 = \frac{1}{2}(\frac{\gamma_{av}}{\varphi})^{i+1}(1-\Gamma(i+1, \frac{\varphi u^2}{\gamma_{av}}))$. By substituting the results of Δ_5, Δ_6 and Δ_7 into (19), the final expression is finally given by

$$\begin{aligned}\Delta_2 \approx& D_1 \sum_{i=0}^{k} \binom{k}{i} (-\frac{\gamma_{th}+1}{\varphi})^{k-i} (\frac{\gamma_{av}}{\varphi})^{1+i} (\Gamma(i+1, \frac{\varphi u^2}{\gamma_{av}}) \\ & - e^{-\varsigma}(\Gamma(i+2)\Gamma(i+1) e^{\frac{\gamma_{av}}{8v}} W_{-(1+i),\frac{1}{2}}(\frac{\gamma_{av}}{4v}) + \Gamma(i+1, \frac{\varphi u^2}{\gamma_{av}}) - 1))\end{aligned} \tag{20}$$

Finally, substituting (19) and (20) into (15), the end-to-end outage probability $Pr(\gamma^k \leq \gamma_{th})$ is obtained.

IV. NUMERICAL RESULTS

In this section, the numerical results of the analyzed end-to-end outage probability for the proposed algorithm are shown in Fig.2-5. It is assumed that the AWGN and block-fading Rayleigh channels are utilized in the system separately and there are K working sensor nodes, where K may take on the values $1, 2, 3, 4$. SNR_{BU}, SNR_{UB} and SNR_{av} are the average received SNR in decibel on the links of UE-to-eNB, eNB-to-UE and SN-to-UE respectively, while SNR_{th} is the SNR threshold in decibel.

In Fig.2, the received SNR from SN to eNB via UE is shown versus SNR_{av}, and all the links are assumed to be AWGN channels. It reveals that when SNR_{UB} is large and K is small, the target performance can be achieved by small SNR_{av}, requiring less transmit power from SN. For example, when $SNR_{th} = 10dB$ and SNR_{UB} is 30dB or 40dB, the required SNR_{av} for different K are almost the same at 10dB. It indicates that the SN does not need additional transmit power to guarantee the target end-to-end SNR. When $SNR_{UB} = 20dB$, it requires SNR_{av} to be larger than SNR_{th}

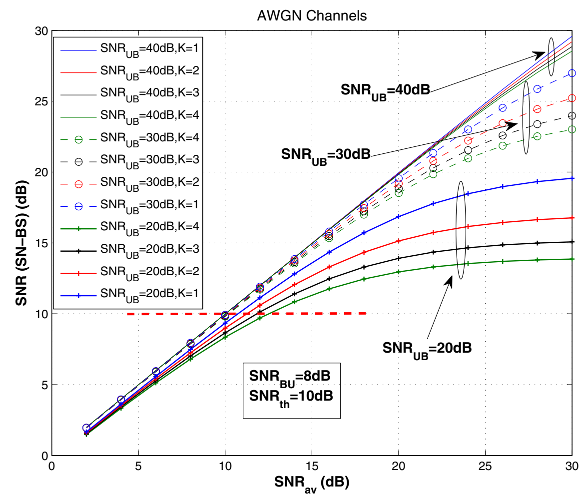

Fig. 2. Comparisons of end-to-end average received SNR in AWGN channels

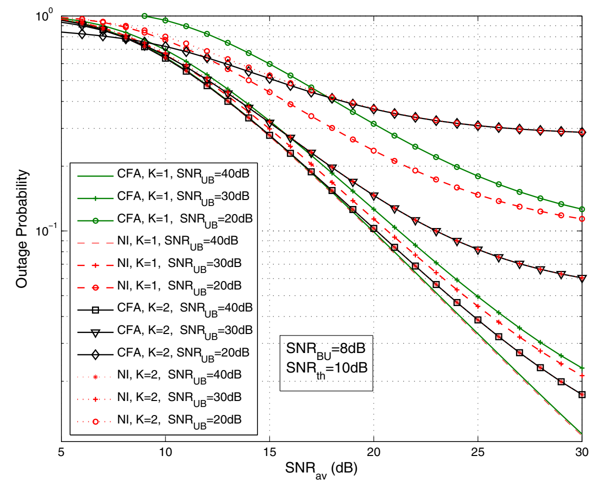

Fig. 3. Comparisons of outage probability of CFA and NI when $SNR_{BU} = 8dB$ and $SNR_{th} = 10dB$

and the difference is from 0.5dB to 2.5dB for $K = 1, \cdots, 4$. Specifically, we have to note that SNR_{th} is depend on the processing gain of MC-CDMA operation. When the number of re-used sub-carriers or the processing gain is large enough, the required SNR_{th} should be vanished. Therefore, the derived approximate closed-form results is significant.

Fig.3, in which SNR_{BU} and SNR_{th} is fixed at 8dB and 10dB respectively, gives an example to show the relationship between the derived closed-form approximation (CFA) and the exact outage probability obtained by numerical integral (NI). When $K = 1$, the closed-form results are overlapped with the true outage probability for large SNR_{UB}, but there is a performance loss for smaller SNR_{UB}. When $K=2$, the closed-form and numerical integral results are identical, which means that the approximate closed-form equations are more accurate for the cases of multiple sensors.

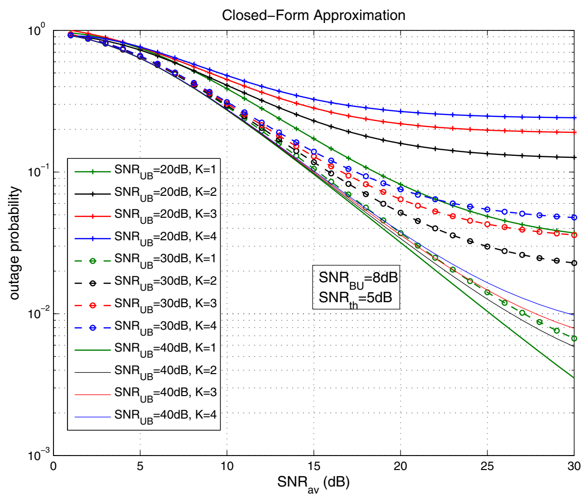

Fig. 4. Comparisons of CFA when $SNR_{BU} = 8dB$ and $SNR_{th} = 5dB$

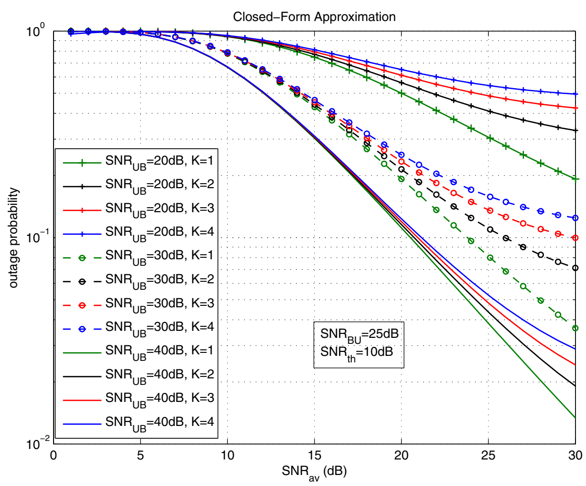

Fig. 5. Comparisons of CFA when $SNR_{BU} = 25dB$ and $SNR_{th} = 10dB$

In Fig.4, SNR_{BU} is also fixed at 8dB, but SNR_{th} is 5dB. After comparing Fig.3 and Fig.4, it is obvious that the smaller SNR_{th} leads to a smaller outage probability at the same SNR_{av}. In Fig.5, although SNR_{BU} is fixed at 25dB, the results are quite similar with Fig.3 when $K = 1, 2$. It implies that the effect of strength of the cellular signals in the re-used spectrum, is quite limited so that the restriction of selecting re-used spectrum is flexible.

V. Conclusion

In this paper, we propose a sensor integration method to LTE/LTE-A networks without increasing the overall spectrum use. The cellular terminal performs as mobile relay with AF relaying protocol and the cellular spectrum is re-used by a group of sensor nodes. By using MC-CDMA method at the sensor transmitters, the data is spread onto the whole re-used spectrum where a low data rate transmission to mobile relay is created. After canceling the cellular components in received overlapped signals, eNB can detect the sensor information from different nodes with advanced multi-user detection method. Then, the end-to-end outage probability of the proposed algorithm is analyzed and a closed-form approximation is derived. Finally, the numerical results show the derived closed-form approximation is effective and the proposed scheme can be used by LTE/LTE-A networks. In the future work, we will investigate the multiple-cell scenario, where the problem of intra/inter-cell interference management is going to be concerned.

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