Superposition Network Coding for wireless Cooperative Communication

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***Abstract*—Cooperative diversity is an innovative approach to improve the reliability of communication. However, this technology is challenging in practice. Time and frequency synchronization of relay nodes in simultaneous based cooperative diversity protocols are very important. Hence, realization of such requirement is difficult. Although separation in transmission time of terminals in traditional time division multiple access (TDMA) method can solve the synchronization problems, but it leads to lower spectral efficiency. In this paper a cooperative strategy is proposed for asymmetric wireless networks that improves overall wireless communication performance in comparison with non-cooperative protocols with high spectral efficiency and non synchronization problems. In this technique, we use a combination of superposition coding and network coding to achieve incremental diversity in asymmetric wireless networks; hence the name superposition network coded cooperation (SNCC). The receiver structure is presented as simple as possible. The error performance of SNCC is analyzed by appropriate approximations and the analytical results are compared with simulation results. The results demonstrate improvement in error performance and the network lifetime.**

***Index Terms*—Cooperative diversity, Symbol Error Rate Selection Combining (SER-SC), Interference Ignorant Detector (IID), Network coding, Superposition coding.**

I. Introduction

COMMUNICATION over a wireless channel is subject to large scale propagation effects including path loss, shadowing, and small scale multipath fading. These are the most important sources of performance degradation [1]. Cooperative communication is a practical approach to mitigate the adverse effects of fading [2]-[3].

The fundamental idea of cooperative communication is based on the cooperation of a group of distributed single antenna terminals to form a virtual multiple antenna system [4].

An important application of cooperative communication is its capability to improve the performance of communication in asymmetric networks. Nodes are distributed in different locations and experience different path-loss and shadowing effects in a wireless network, hence different channel conditions. This makes wireless networks asymmetric in nature. Direct transmission in asymmetric wireless networks results in high aggregate transmit power and uneven power distribution that reduces network lifetime [5]. Cooperative diversity is a technique to improve the performance of communication in asymmetric networks [5].

Although cooperative communication is a practical solution to improve the performance of wireless systems, it has its own challenges. The performance analysis of multi-relay decode-and-forward (DF) and amplify-and-forward (AF) protocols using conventional repetition coding was studied in [6]-[9]. For these protocols, the relay nodes transmit in orthogonal time slots in the time division multiple access (TDMA) method. This is a low complexity approach. However, it leads to low spectral efficiency due to large time delay [4]. The spectral efficiency in TDMA-based protocols depends on the number of relay nodes. So, these protocols are not efficient for networks with large numbers of relays at all. To improve the system spectral efficiency, simultaneous-based protocols are proposed [10]-[13], in which relay nodes transmit in the same time slot. These strategies make a significant improvement of spectral efficiency at the cost of perfect time and frequency synchronization of the relay nodes [14]-[15]. This requirement for synchronization is very difficult to be satisfied due to the distributed nature of cooperative communication [16].

The above review clarifies the necessity of introducing new frameworks for cooperation in asymmetric networks with high spectral efficiency without synchronization problems. In [15] a new cooperation strategy has been proposed that eliminates synchronization problems with low transmission delay. However, this approach does not improve spectral efficiency at all.

In this paper a new cooperative diversity scheme for multipoint-to-point communication in asymmetric networks is proposed. We assume an asymmetric network that multiple source nodes transmit their information symbols to a common destination by the use of relay nodes. We overcome the synchronization problems by avoiding simultaneous transmission of terminals. Therefore, we use the TDMA approach for transmission. In this case, in order to overcome the low spectral efficiency problem, a technique named superposition coded cooperation (SCC) is used. The idea of SCC is based on merging source and relay transmission phases. In this technique a source node appears simultaneously as relay for other nodes in its transmission phase [17]-[21]. One approach for realization of SCC is that the source node assigns a fraction of its power to transmit its own information and the remainder for relaying [17]. Clearly, a drawback of this technique is its inefficiency when the amount of relaying information increases.

In the proposed scheme, conventional superposition modulation is modified by network coding [22], so that it can be used for arbitrary amount of relaying information. The idea is based on mapping all the relaying symbols to one symbol by bit level XOR. Reducing relaying symbols to one symbol makes superposition modulation efficient. This technique is called superposition network coded cooperation (SNCC). In this paper, SNCC is proposed for a simple but generalizable case. We analyze and simulate symbol error rate (SER) performance of SNCC for three users with M-PSK modulation. The simulation results show that SNCC may be used to achieve an even power distribution in the asymmetric network. Also, in comparison with noncooperative transmission, SNCC can provide an improvement in the error performance of the first and the second terminals with an arbitrarily small degradation of the third terminal for sufficiently high signal-to-noise ratio (SNR). This issue proves the advantage of SNCC in the error performance improvement in comparison with noncooperative transmission. All of these advantages are provided by SNCC, while it does not require any extra time or frequency resources in comparison with the noncooperative scheme.

The rest of this paper is organized as follows. Section II provides a system model. Section III elaborates the analysis behind the SNCC idea. Simulation results are presented in Section IV and finally a conclusion is drawn in Section V.

II. System Model

We consider an asymmetric network consisting of N source nodes denoted by $U_1, U_2, .., U_N$ transmitting information to a common destination in a TDMA manner. Every source node can appear as a half-duplex relay node. Cooperation strategy for each relay is DF. The communication channel between every node and destination is modelled as narrowband Rayleigh fading with additive white Gaussian noise (AWGN) [1]. The set of network terminals are partitioned into some groups with at most three members. Although we assume three nodes in this paper, our study reveals that the proposed method can be generalized to $n > 3$ nodes. Grouping criterion is based on true detection. In this manner every terminal must be able to decode the information of other terminals in its group with negligible error.

Here, we consider a three member group. Without loss of generality, terminals are indexed according to their channel quality so that the terminal with lower channel quality has a lower index number. Priority of transmission is also determined according to channel quality, where the terminal with the worse channel quality transmits earlier. The terminal $U_i, i = 1, 2, 3$, transmits in the ith time slot. The transmitted signal from U_i is received by the terminal $U_j, i < j \leq 4$, where the index $j = 4$ denotes the destination. The received signal at the terminal U_j, can be written as

$$y_{i,j} = h_{i,j} x_i + v_{i,j}, \quad j = i + 1, \cdots, 4, \tag{1}$$

where $h_{i,j}$ is the channel coefficient between the terminals i and j and the coefficient $h_{i,4} \sim \mathcal{CN}(0, \frac{1}{\lambda_i})$ represents the channel between the ith terminal and destination. Also, $v_{i,j}$ is zero mean AWGN with variance N_0. The signal x_i, transmitted by the terminal U_i, is

$$x_i = c_{1,i} s_i + \sqrt{1 - c_{1,i}^2}\, s_{1,\cdots,i-1}, \quad i = 1, 2, 3, \tag{2}$$

where the symbol $s_i, i = 1, \cdots, 3$, is the source symbol of ith terminal. The superposition factor $c_{1,i}$ is

TABLE I
Transmission scheme in SNCC

Transmission	U_1 Transmit s_1	U_2 Transmit (s_2, s_1)	U_3 Transmit $(s_3, s_1 \oplus s_2)$
Time slot	1	2	3

$$c_{1,i} = \begin{cases} 1, & i = 1; \\ c_1, & i \neq 1, \end{cases} \tag{3}$$

where the coefficient c_1 is close (but not equal) to 1. The source symbols are chosen independently from an equiprobable M-PSK constellation with average power $E\left[|s_i^2|\right] = a^2$. Also, the superposed symbol $s_{1,\cdots,i-1}$ is defined as

$$s_{1,\cdots,i-1} = s_1 \oplus s_2 \oplus \cdots \oplus s_{i-1}, \tag{4}$$

where $\oplus$ denotes bit level XOR between two symbols. The symbol $s_{1,\cdots,i-1}$ has the same constellation order and average power as source symbols. According to (2), the transmitted symbol from the ith terminal consists of the information of the symbols $s_1, s_2, \cdots, s_i$.

To summarize, the transmission scheme is presented in Table I. According to the described model of SNCC, this technique requires no extra time and bandwidth resources compared to the TDMA-based non-cooperative scheme. This makes the spectral efficiency higher than other cooperative schemes that are based on TDMA. In addition to high spectral efficiency, SNCC has no synchronization challenges because of the fact that the terminals transmit in orthogonal time slots [15].

III. Analysis of SNCC

In this section the receiver structure and SER analysis of SNCC for a three user group are presented. When the transmission phase of terminal U_i is finished, the next transmitting terminals $U_j, i < j \leq n$ receive $y_{i,j}$ and, in the role of relay nodes, detect the source symbol s_i by the use of an interference ignorant detector (IID) given as [23]

$$\hat{s}_i = \underset{s_i}{\arg\min} \; |y_{i,j} - h_{i,j} c_{1,i} s_i|. \tag{5}$$

According to (5), IID detects the desired symbol s_i by ignoring the presence of intentional interfering symbol $\sqrt{1 - c_{1,i}^2}\, s_{1,..,i-1}$. This issue provides low complexity for detection. However, the performance of IID is highly sensitive to interference. Exceeding the interfering power from a specific threshold makes an error floor in detection [23]. This error floor makes it impossible to achieve arbitrarily low error probability for detection, hence causing high degradation in detection performance [23]. Since the superposed symbol appears as interference, the interference is controllable in SNCC. This means that the superposed symbol can be designed so that IID has efficient performance. To satisfy the condition for optimal maximum likelihood (ML) performance of IID, we choose the superposed symbol $s_{1,..,i-1}$ from an M-PAM constellation rotated by an angle equal to phase of the source symbol s_i. In this case, (1) can be written as

$$\begin{aligned} y_{i,j} &= h_{i,j}(c_{1,i}s_i + \sqrt{1-c_{1,i}^2}e^{j\varphi_{s_i}}s_{1,\cdots,i-1}) \\ &+ \upsilon_{i,j}, \quad j = i+1, \cdots, 4, \end{aligned} \tag{6}$$

where s_i and $s_{1,..,i-1}$ are the source symbols in M-PSK modulation and superposed symbol in M-PAM modulation respectively. Also, φ_{s_i} is the phase of the symbol s_i. In this manner, the transmitted symbols of the second and the third terminals are selected from the set ψ given as

$$\psi = \{(c_1 + A_m\sqrt{\tfrac{3(1-c_1^2)}{M^2-1}})ae^{j\frac{2\pi n}{M}}\}, \quad m,n = 1,2,\cdots,M \tag{7}$$

where $A_m = 2m - 1 - M$. As shown in appendix, if we set

$$c_1 + A_m\sqrt{\tfrac{3(1-c_1^2)}{M^2-1}} > 0, \quad m = 1,2,\cdots,M, \tag{8}$$

which is satisfied by $c_1 > \sqrt{\frac{3}{4}\cdot\frac{M-1}{M-.5}}$, the IID has the same performance as ML detector in detecting the source symbol s_i from $y_{i,j}$. This condition could be always satisfied if the coefficient c_1 is sufficiently close to 1.

The performance of communication in a wireless network depends on the detection method used at the destination. Implementation of optimum receiver for SNCC at the destination is not possible because of high complexity. So, it is necessary to propose a receiver structure with low complexity that exploits the benefits of SNCC. The proposed scheme for detection at destination is based on symbol error rate selection combining (SER-SC) [24] and successive interference cancellation (SIC) [23]. In this approach, the receiver waits for all the signals of a group to be received. According to (6), the received signals at the destination after three time slots are

$$\begin{cases} y_1 = h_1 s_1 + \nu_1, \\ y_2 = h_2\left(c_1 s_2 + \sqrt{1-c_1^2}e^{j\varphi_{s_2}}s_{1,1}\right) + \nu_2, \\ y_3 = h_3\left(c_1 s_3 + \sqrt{1-c_1^2}e^{j\varphi_{s_3}}s_{1,2}\right) + \nu_3, \end{cases} \tag{9}$$

where the index $j = 4$ is removed for simplicity. After that, the destination begins the detection process from the last to the first received signal.

In the first phase, the receiver detects the source symbol s_3 from y_3 by IID. By the use of the nearest neighbor union bound (NNUB) approximation [25], the instantaneous error probability for detecting the source symbol s_3 from y_3 by IID can be approximately given by [26]

$$P_{es_3} \approx \frac{2}{M}\sum_{m=1}^{M} Q\left[u_m\sqrt{2|h_3|^2\text{SNR}}\right], \tag{10}$$

where SNR$=\frac{a^2}{N_0}$ and

$$u_m = \left(c_1 + A_m.\sqrt{\frac{3(1-c_1^2)}{M^2-1}}\right)\sin(\frac{\pi}{M}). \tag{11}$$

By averaging (10) with respect to exponential random variable $|h_3|^2 \sim \exp(\lambda_3)$, the approximate average SER is given by

$$P_{es_3,avg} \approx \frac{2}{M}\sum_{m=1}^{M}\left(\frac{1}{2} - \frac{1}{2}\sqrt{\frac{u_m^2\text{SNR}}{u_m^2\text{SNR}+\lambda_3}}\right). \tag{12}$$

In high SNR, by the use of two first terms of the Taylor expansion, (12) can be approximated as

$$P_{es_3,avg} \approx \frac{1}{2M\text{SNR}}\sum_{m=1}^{M}\left(\frac{\lambda_3}{u_m^2}\right). \tag{13}$$

As we can see from (13), the SER is a function of SNR^{-1}, so the diversity order is equal to 1.

After detecting the symbol s_3, the receiver tries to remove the effect of source symbol s_3 from y_3 through the detected symbol $\hat{s}_3$ as

$$\hat{y}_3 = e^{-j\varphi_{\hat{s}_3}}\left(y_3 - c_1 h_3 \hat{s}_3\right), \tag{14}$$

where $\varphi_{\hat{s}_3}$ is the phase of detected symbol $\hat{s}_3$.

In the second phase, the receiver detects the source symbol s_2. The information of this symbol is placed in signals y_2 and $\hat{y}_3$. Hence, it is possible for the receiver to gain the advantages of diversity in detection of s_2. However, the symbol s_2 does not explicitly exist in $\hat{y}_3$ due to bit level XOR. This issue makes it impossible to utilize a conventional maximal ratio combiner (MRC). Our approach to achieve spatial diversity is based on SER-SC. In this technique, the receiver selects a path among all received paths with minimum instantaneous SER and detects a desired symbol from it. If the selected signal is y_2, then the symbol s_2 is directly detected by IID. Otherwise, the IID detects the superposed symbol $s_{1,2}$ from $\hat{y}_3$ and the symbol s_1 from y_1 and then calculates their bit level XOR. Clearly, in this case the resulted symbol will be s_2 if the symbols $s_{1,2}$ and s_1 are detected correctly. The decision making in this phase is given as

$$\hat{s}_2 = \begin{cases} \hat{s}_2(y_1,\hat{y}_3), & P_{c_1}.P_{c_3} > P_{c_2}, \\ \hat{s}_2(y_2), & \text{otherwise.}, \end{cases} \tag{15}$$

where $\hat{s}_2(y_2)$ and $\hat{s}_2(y_1,\hat{y}_3)$ represent the detected symbol s_2 from y_2 and the pair $(y_1,\hat{y}_3)$ respectively. Also P_{c_1}, P_{c_2}, and P_{c_3} are the instantaneous probability of correct detection of the symbols s_1 from y_1, s_2 from y_2, and $s_{1,2}$ from $\hat{y}_3$ respectively. According to (15), the instantaneous error probability in this phase can be written as

$$P_{e_{s_2}} = \begin{cases} 1 - P_{c_1}.P_{c_3}, & P_{c_1}.P_{c_3} > P_{c_2}, \\ 1 - P_{c_2}, & \text{otherwise.} \end{cases} \tag{16}$$

By the use of Bayes rule we have

$$\begin{aligned} P_{c_3} = & \quad 1 - P_{es_{1,2}|cs_3} - P_{es_3} \times \\ & \left(P_{es_{1,2}|es_3} - P_{es_{1,2}|cs_3}\right) \\ \approx & \quad 1 - P_{es_{1,2}|cs_3} \\ \approx & \quad 1 - 2Q\left(\sqrt{\tfrac{6(1-c_1^2)}{M^2-1}|h_3|^2\text{SNR}}\right), \end{aligned} \tag{17}$$

where $P_{.|.}$ denotes the conditioned instantaneous error probability and the notations es_i and cs_i represent false and correct detection of s_i respectively. The first approximation in (17) is valid due to the fact that P_{es_3} is considerably less than $P_{es_{1,2}|cs_3}$ for c_1 near to 1. The second approximation is achieved by NNUB approximation. Also, by the use of NNUB we have

$$P_{c_1} \approx 1 - 2Q\left(\sin(\frac{\pi}{M})\sqrt{2|h_1|^2\text{SNR}}\right), \tag{18}$$

and

$$P_{c_2} \approx 1 - \frac{2}{M}\sum_{m=1}^{M} Q\left[u_m\sqrt{2|h_2|^2\mathrm{SNR}}\right], \tag{19}$$

respectively, where the term u_m is given by (11). To get the average error probability of detecting the symbol s_2, we have to average (16) over the joint probability density function (PDF) of P_{c_1}, P_{c_2}, and P_{c_3}. Taking the average is not possible because there is not a known expression for the PDF of these random functions. Therefore, we approximate the random functions $P_{c_1} \cdot P_{c_3}$ and P_{c_2} with the simpler random functions Y_1 and Y_2 respectively, so that for high SNR we have

$$\begin{gathered} E\left[Y_1\right] \approx E\left[P_{c_1}.P_{c_3}\right], \\ E\left[Y_2\right] \approx E\left[P_{c_2}\right], \end{gathered} \tag{20}$$

where $E[.]$ denotes the expected value. We define Y_1 and Y_2 as

$$\begin{gathered} Y_1 = 1 - 2Q(\sqrt{|h|^2\mathrm{SNR}}), \\ Y_2 = 1 - 2Q(\sqrt{2\alpha\sin^2(\frac{\pi}{M})|h_2|^2\mathrm{SNR}}), \end{gathered} \tag{21}$$

where $|h|^2$ is an exponential random variable with mean $\frac{1}{\lambda}$ and the coefficient α is a constant. With some simple computations we find that (20) will be satisfied if

$$\lambda = \frac{(M^2-1)\lambda_3}{6(1-c_1^2)} + \frac{\lambda_1}{2\sin^2(\frac{\pi}{M})} \tag{22}$$

and

$$\alpha = \frac{M}{\sum_{m=1}^{M}\frac{1}{\left(c_1 + A_m\sqrt{\frac{3(1-c_1^2)}{M^2-1}}\right)^2}}. \tag{23}$$

By replacing the terms in (16) with their approximations in (21), we have

$$P_{es_2} \approx \begin{cases} 2Q(\sqrt{|h|^2\mathrm{SNR}}), & 2\alpha\sin^2(\frac{\pi}{M})|h_2|^2 < |h|^2, \\ 2Q(\sqrt{2\alpha\sin^2(\frac{\pi}{M})|h_2|^2\mathrm{SNR}}), & \text{otherwise.} \end{cases} \tag{24}$$

where the intervals are simplified due to a monotonically decreasing manner of the Q-function. We can simplify (24) as

$$P_{e_{s_2}} \approx \begin{cases} 2Q(\sqrt{X_1}), & \text{if } X_1 > X_2, \\ 2Q(\sqrt{X_2}), & \text{otherwise.} \end{cases} \tag{25}$$

where X_1 and X_2 are exponential random variables defined as

$$\begin{aligned} X_1 &\triangleq |h|^2\mathrm{SNR} \sim \exp(\frac{\lambda}{\mathrm{SNR}}), \\ X_2 &\triangleq 2\alpha\sin^2(\frac{\pi}{M})|h_2|^2\mathrm{SNR} \sim \exp(\frac{\lambda_2}{2\alpha\sin^2(\frac{\pi}{\mathrm{M}})\mathrm{SNR}}) \end{aligned} \tag{26}$$

By averaging (25) over the joint PDF of independent random variables X_1 and X_2 given by (26), the average SER for detection of s_2 is approximately equal to

$$P_{es_2,avg} \approx 1 - \frac{1}{\sqrt{1+2\lambda_3}} + \frac{1}{\sqrt{1+2\lambda_3+2\lambda_4}} - \frac{1}{\sqrt{1+2\lambda_4}}, \tag{27}$$

where $\lambda_3 = \frac{\lambda}{\mathrm{SNR}}$ and $\lambda_4 = \frac{\lambda_2}{2\alpha\sin^2(\frac{\pi}{M})\mathrm{SNR}}$. By the use of Taylor expansion, (27) at high SNR can be expressed approximately as

$$P_{es_2,avg} \approx \frac{3\lambda\lambda_2}{2\alpha\sin^2(\frac{\pi}{M})\mathrm{SNR}^2} \tag{28}$$

varying $P_{es_2,avg}$ as a function of SNR^{-2} shows the diversity gain equal to 2 in detection of s_2.

After detecting s_2, its effect is removed from y_2 with the same manner as (14), to create $\hat{y}_2$. Then the detection phase of s_1 is started. In this phase, the receiver has three paths y_1, $\hat{y}_2$, and $(y_2, \hat{y}_3)$ for detection. Detection from y_1 or $\hat{y}_2$ is performed directly by IID. On the other hand, if the signal $\hat{y}_3$ is selected, firstly the symbol $s_{1,2}$ is detected by IID and secondly the symbol s_1 is extracted by bit level XOR of the detected symbol $\hat{s}_{1,2}$ and the symbol $\hat{s}_2$, detected in the second phase according to (15). So, the decision approach is given by

$$\hat{s}_1 = \begin{cases} \hat{s}_1(y_1), & \text{if } P_{c_1} > P_{c_4}, P_{c_2}.P_{c_3}, \\ \hat{s}_1(\hat{y}_2), & \text{if } P_{c_4} > P_{c_1}, P_{c_2}.P_{c_3}, \\ \hat{s}_1(y_2, \hat{y}_3), & \text{otherwise.}, \end{cases} \tag{29}$$

where $\hat{s}_1(y_1)$, $\hat{s}_1(\hat{y}_2)$, and $\hat{s}_1(y_2, \hat{y}_3)$ represent detected symbol s_1 from y_1, $\hat{y}_2$, and the pair $(y_2, \hat{y}_3)$ respectively. Also, P_{c_4} is the instantaneous probability of correct detection of symbol $s_{1,1}$ from $\hat{y}_2$ and is approximated with the same manner as (17) by replacing h_3 with h_2. In this phase the paths $\hat{y}_2$ and $(y_2, \hat{y}_3)$ are not independent. Therefore we expect a diversity gain of less than 3. In this case we do not provide analytical expression for average error probability due to its difficulty and suffice to simulation results.

IV. Simulation Results

In this part we present computer simulations for SNCC scheme in a three user group. The SNCC scheme requires the same bandwidth and time slots as the noncooperative scheme. Therefore, we compare SNCC performance with the direct transmission scheme.

Fig. 1 shows SER performance versus SNR for the terminals with $\lambda_1 = 1$, $\lambda_2 = .1$ and $\lambda_3 = .05$ and 4-PSK modulation for the source symbols. We choose the superposition factor c_1 equal to 0.93. The excellent agreement between simulation results and analytical results demonstrates the accuracy of our analysis for SNCC. In this figure, we also compare SNCC performance with repetition based cooperative scheme with the same overall power consumption as SNCC, as shown in table II. In this case, the required time slots for a group of three users is two times larger than that of SNCC. By comparing the decaying slope of the curves we can infer that the first and the second terminals exploit a higher diversity order in the SNCC scheme than the noncooperative scheme. This issue ensures an increase in the improvement of performance in these terminals when the SNR increases. This improvement is at the cost of a fix performance degradation for all amounts of SNR for the third terminal.

A criteria for choosing the coefficient c_1 can be based on achieving approximately the same performance of all terminals in a specific SNR. This criteria refers an approach to achieve even power distribution in the network, which results in increasing the network lifetime. Fig. 2 shows SER performance for a three user group with 16-PSK modulation of source

TABLE II
TRANSMISSION SCHEME IN REPETITION CODING WITH THE SAME POWER CONSUMPTION AS SNCC

Transmission	U_1 Transmit s_1	U_2 Transmit $c_1 s_2$	U_3 Transmit $\sqrt{1-c_1^2}s_1$	U_3 Transmit $c_1 s_3$	U_3 Transmit $\sqrt{\frac{1-c_1^2}{2}}s_2$	U_3 Transmit $\sqrt{\frac{1-c_1^2}{2}}s_1$
Time slot	1	2	3	4	5	6

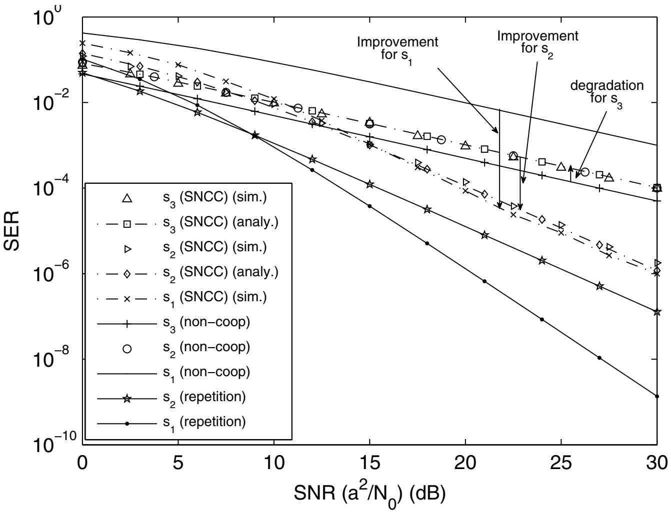

Fig. 1. SER performance of SNCC for 4-PSK modulation, c_1 = .93, λ_1 = 1, λ_2 = .1, λ_3 = .05.

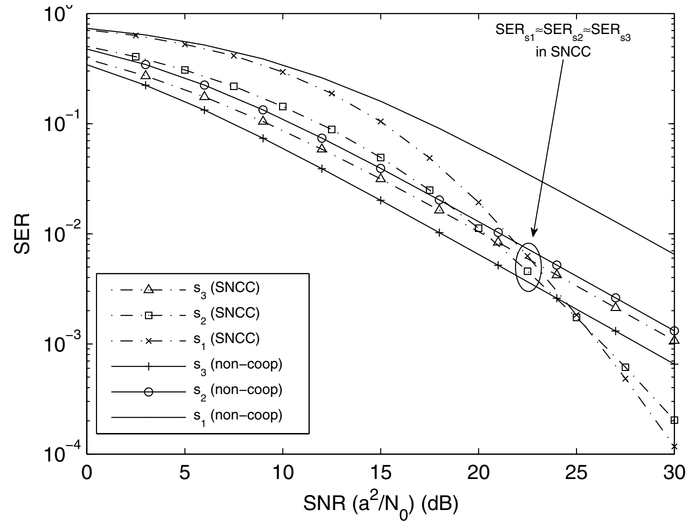

Fig. 2. SER performance of SNCC for 16- PSK modulation, c_1 = .95, λ_1 = .5, λ_2 = .1, λ_3 = .05.

symbols and λ_1 = .5, λ_2 = .1 and λ_3 = .05. We can see from Fig. 2 the SER performance of terminals in non-cooperative scheme is significantly different in SNR=22.5 dB. By choosing c_1 = .95 in SNCC scheme we can achieve approximately the same SER for all the terminals in SNR=22.5 dB.

By comparing SER curves in SNCC scheme with the same curves in non-cooperative scheme (Fig. 1, 2) we can easily see that SNCC scheme provides higher diversity orders for the first and the second terminals with no reduction in diversity order of the third terminal. Therefore in comparison with noncooperative scheme, SNCC can provide significant improvement for the first and the second terminals at the cost of an arbitrarily small degradation of the third terminal for a sufficiently large SNR. This is the major advantage of SNCC to non-cooperative communication. We note that this important advantage is achievable without any extra resource requirement compared to the noncooperative scheme.

Fig. 3 depicts SER performance of the terminals in the first example for various amounts of c_1 in SNR=15 dB. As shown in this figure, SNCC scheme makes significant performance improvement for the first and the second terminals at the cost of a negligible degradation of the third terminal for the superposition factors close to one (.96 < c_1 < .99). Therefore, these values can be selected if we need very small degradation of the third terminal.

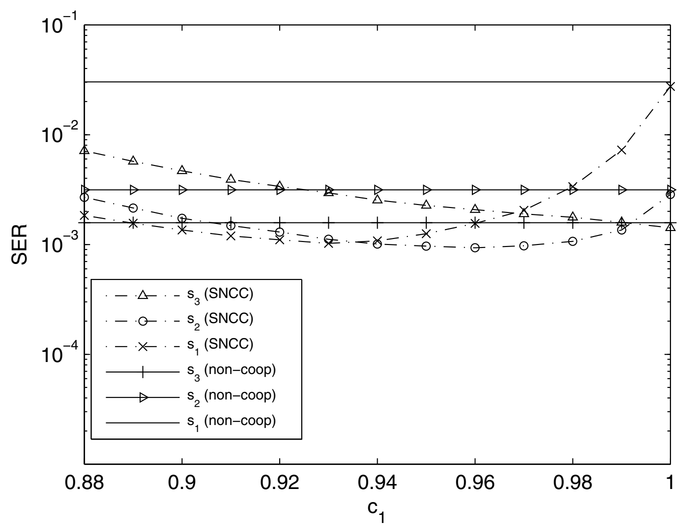

Fig. 3. SER performance versus superposition factor for 4-PSK modulation, λ_1 = 1, λ_2 = .1, λ_3 = .05, SNR = $15dB$.

V. CONCLUSION

In this paper, we proposed a new cooperation scheme for asymmetric wireless networks to achieve better communication performance than non-cooperative schemes with high spectral efficiency and non synchronization problems. The objective was realized by the use of a combination of superposition coding and network coding in a group with three users. This scheme was named as SNCC. In comparison with non-cooperative communication, the SNCC can provide significant improvement for the first and the second terminals at the cost of an arbitrarily small degradation of the third terminal for a sufficiently large SNR. This advantage is provided by SNCC without any extra transmission resources compared to the noncooperative scheme.

$$
\begin{aligned}
r_k &= \left\{ r : |r - h_i c_1 a e^{j\frac{2\pi}{M}k}| < |r - h_i c_1 a e^{j\frac{2\pi}{M}z}| \quad \forall z \neq k \right\} \\
&= \left\{ r : |r - h_i a e^{j\frac{2\pi}{M}k}(c_1 + A_m\sqrt{\frac{3(1-c_1^2)}{M^2-1}})| < |r - h_i a e^{j\frac{2\pi}{M}z}(c_1 + A_m\sqrt{\frac{3(1-c_1^2)}{M^2-1}}) \quad \forall z \neq k, \forall A_m \right\} \\
&= \left\{ r : \sum_{A_m} e^{-\frac{|r - h_i a e^{j\frac{2\pi}{M}k}(c_1 + A_m\sqrt{\frac{3(1-c_1^2)}{M^2-1}})|^2}{N_0}} > \sum_{A_m} e^{-\frac{|r - h_i a e^{j\frac{2\pi}{M}z}(c_1 + A_m\sqrt{\frac{3(1-c_1^2)}{M^2-1}})|^2}{N_0}} \quad \forall z \neq k \right\}
\end{aligned} \tag{30}
$$

VI. APPENDIX

In this part we show that if the condition in (8) is satisfied then IID in detecting the source symbol s_i from $y_{i,j}$ in (6) has the same performance as optimal ML detector. According to (5), the decision area for IID to detect the kth constellation point of s_i is presented at the top of this page, where the second equality is valid if (8) is satisfied. Also the right hand side expression in the third equality is the decision area for an optimal ML detector to detect kth constellation point of s_i from $y_{i,j}$ [23].

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