ISITC 2016

International Symposium on Information Technology Convergence

October 13–15, 2016
Shanghai University of Engineering Science, China
http://seee.sues.edu.cn/ISITC2016

Session 1-C： **Human-Computer Interaction & Robotics**

13:30-17:00, October 14, 2016. No.5 Lecture Hall

Session Chairs:
Jucheng Yang (Tianjin University of Science and Technology, China)
Oubong Gwun (Chonbuk National University, Korea)

Transmitter Cooperation with 5 and 8 User Topological Interference Management

Sunil chinnadurai, Poongundran Selvaprabhu, Yongchae Jeong, Moon Ho Lee
Department of Electronics and Information,
Chonbuk National University, Jeonju, South Korea
Email- sunilkcsss@jbnu.ac.kr, poongundrano7@gmail.com, ycjeong@jbnu.ac.kr, moonholee@jbnu.ac.kr

Abstract—**In this paper, we investigate the analogy between the conventional topological interference management (TIM) with proposed network topologies such as 5 prime substances (5 user networks) and 8 trigram (8 user networks). The key observation is that optimal symmetric degree of freedom (DoF) can be achieved for 5 user network with different channel coherence times by adaptively selecting the interference alignment scheme via controlling the alignment feasibility of the transmitted signals. However, this yields a very complex problem, for which we use the combination of different schemes such as interference avoidance and repetition coding. In addition to the above schemes, we propose a triangular transmit cooperation (TTC) algorithm for 8 user networks to achieve the optimal symmetric DoF. Theoretical results demonstrate the effectiveness of the proposed 5 and 8 user networks are well matched to the wireless mobile channel environment to achieve the symmetric DoF for different channel coherence times which ensures that the proposed networks are applicable for dense wireless network applications.**

Keywords—coherence time; degree of freedom; triangular transmit cooperation; 5 prime substance; 8 trigram;

I. INTRODUCTION

The principle of oriental five primary substances describes two cycles known as construction (outer) and destruction (inner) cycle. The most fascinating part about this principle is that the construction cycle is co-operative to each other and the destruction cycle is non-cooperative or conflict to each other substances [1]. This principle nature has motivated us to think about the joint utility of these two cycles as a 5-user network topology in Topology Interference Management (TIM) where there is no channel state information at the transmitter (CSIT). Another interesting point to observe is that the transmitter and receiver information sets of this 5-user network has modulo-3 functionality (i.e T_m-1 = R_n-4) between them which makes it unique and practically feasible network topology in modern wireless communication systems. The remaining part of this work is based on the eight fundamental principles of reality which are called as eight trigrams because of their tripartite structure. Eight trigrams (or 8-user network topology) are symmetric in nature and also they have no conflict within themselves as in five user networks. Trigrams follows Triangular Transmit Co-operation (TTC), where the two symmetric transmitters co-operate with each other to help the third transmitter. The above functionality makes this topology more special and highly applicable to dense wireless networks where the transmitter co-operation is in great necessity to achieve the optimal symmetric degree of freedom (DoF) in these networks. As wireless networks grow in size and mobility increases, the availability of CSI at the transmitters (CSIT) becomes a formidable task to undertake. In this work, we lay emphasis on the impact of knowledge about network topology on interference management in interference networks. We consider an interference network with M transmitters and N receivers, where each transmitter aims to send messages to its corresponding receiver [2-6]. We also assume that the transmitters are only aware of network topology and they do not know the actual channel gain values. In this paper, we focus on the slow fading as well as fast fading scenario (channel gain values are independent and identically distributed across all users in the network) with only network topology knowledge at the nodes. In slow fading, channel coherence time ($\tau_c \geq 4$) and the desired messages are delivered from transmitters to all the receivers within certain time slots whereas the time slots are increased for fast fading channels with coherence time (τ_c) =1.

The main contributions of this paper are as follows. Using the interference alignment approach used in [3] for the proposed network topologies, optimal symmetric DoF is achieved for different channel coherence times. Alignment feasible graph is drawn for both the 5 & 8 user network topologies which show the feasibility of interference alignment between any two messages. The rest of the paper is organized as follows. We describe the system model in Section II. In Section III, we propose 5-user & 8-user network topologies achieving the optimal symmetric DoF. Concluding remarks are summarized in Section IV.

II. SYSTEM MODEL AND PROBLEM FORMULUATION

A. System Model

We consider a K-user partially connected cellular network which has equal number of M transmitter nodes and N receiver nodes where each node is equipped with single antenna. The received signal for receiver n at each time slot t is denoted by Y_n (t) € C is given by

$$Y_n(t) = \sum_{m\in T_n} X_m(t) h_{nm}(t) + Z_n(t) \qquad (1)$$

Where X_m is the transmitted signal, h_{nm} being the channel coefficient between the transmitter and receiver at time slot t and Z_n is the additive white gaussian noise with independent and identically distributed zero mean and unit variance. The channel coefficient h_{nm} will be zero if the transmitter is not connected to receiver and the non-zero channel coefficients are i.i.d across all the users, transmit symbols & time. The set which consists of transmitter indices connected to receiver n are denoted by $\{T_m\}_{m=1}^{K}$ and the set of receiver indices that are connected to transmitter m are denoted by $\{R_n\}_{n=1}^{K}$, where $k \in \{1, 2, 3, ..K\}$. The average transmit power constraints are given as

$$E\left(\frac{1}{f}\left|X_m^f(t)\right|^2\right) \le P \qquad (2)$$

The messages are encoded to a vector $X_m^f \in C^n$ before transmitting them through wireless channel to receivers within f time slots. Encoding of the messages are done based on the network topology and the distribution of the non- zero channel coefficients i.e. Transmitter and receiver sets for all users. The receiver decodes the received signal vector Y_n^f to recover its desired message where h_{ji}^f denotes the vector of the channel coefficients from transmitter X_m to receiver Y_n within f time slots.

B. Problem Formulation

The symmetric degree of freedom for the 5 user and 8 user interference networks will be formulated in this paper with the help of channel gain distribution and adjacency matrix or network topology known by all the transmitters and receivers.

In general, the symmetric DoF is defined as follows

$$d_{sym} = \lim_{P\to\infty}\frac{R_m(P)}{\log(P)} \qquad (3)$$

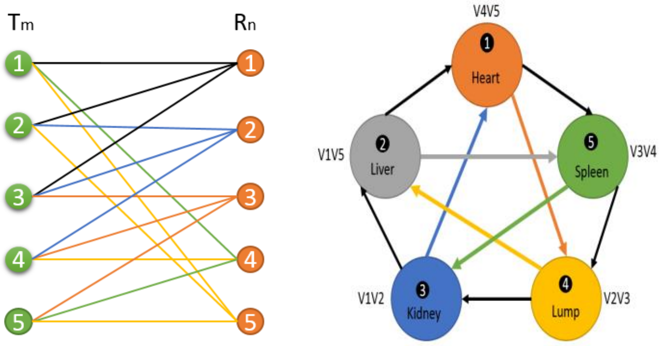
Where R is the rate, P is the transmission power and d is the degree of freedom. In this paper, block fading channel is considered where the channel coefficients vary independently from one coherence time to another coherence time.

III. INTERFERENCE ALIGNMENT SCHEME FOR PROPOSED MODEL

In this section, we will introduce our proposed network topologies i.e. 5 user Network and 8 user Network (we call them as 5 prime substances and 8 trigrams respectively). We also present their interference alignment schemes and the achievable symmetric DoF are derived for both these topologies.

A. 5 users as 5-Prime Substances

Definition 1: The interaction between the five prime substances are co-operative for outer cycle (represented by black arrows) and conflict with each other for inner cycle (orange arrows).



(a) (b)

Fig.1. (a) A (5, 3) regular cellular network topology and (b) its alignment feasibility graph (modulo 3) functionality

Transmitter sets T_k and Receiver sets R_k are obtained from the network topology and they are written as follows.

$T_1=\{1,4,5\}$,$T_2=\{1,2,5\}$,$T_3=\{1,2,3\}$,$T_4=\{2,3,4\}$,$T_5=\{3,4,5\}$ & $R_1=\{1,2,3\}$,$R_2=\{2,3,4\}$,$R_3=\{3,4,5\}$,$R_4=\{1,4,5\}$,$R_5=\{1,2,5\}$.

Where T_m and R_n sets follows modulo 3 operation (i.e transmit set T_1 is similar to receiver set R_4 and T_2 is similar to R_5 and so on). We also assume a, b, c, d & e are the messages desired by five receivers from R_n 1 to R_n 5 respectively with the subscript denoting different symbols for the same receiver. The symbols are precoded with five random vectors denoted by V_1, V_2, V_3, V_4, $V_5 \in C^{4x1}$, where any four vectors are linearly independent covering four dimensional subspace. These symbols will be sent by the transmitters within 4 time slots as below

$X_1=V_1d_1+V_2e_1$, $X_2=V_2a_1+V_3e_2$ (4)

$X_3=V_3a_2+V_4b_1$, $X_4=V_5b_2+V_4c_1$, $X_5=V_1c_2+V_5d_2$ (5)

Where $X_m \in C^{4x1}$ is the vector of the concatenated transmit signals from transmitter m with each element being the transmitted signal at each corresponding time slot. We consider the channel coherence time as $\tau_c \ge 4$, during which the channel coefficients keep constant. Interference alignment scheme with the above coherence time for 5-user network is given in fig.2 (b). For example, we express the received signal at receiver 1 within four time slots with $R_1 = \{1, 2, 3\}$ as

$$Y_1 = h_{11}X_1 + h_{12}X_2 + h_{13}X_3 + Z_1 \qquad (6)$$

$$= h_{12}V_2a_1 + h_{13}V_3a_2 + V_1h_{11}d_1 + V_2h_{11}e_1 + V_3h_{12}e_2 + V_4h_{13}b_1 + Z_1$$

Where the first two terms in the above equation carries desired signal a_1 and a_2 spanned by two dimensional interference free subspaces V_2 and V_3 respectively. The next four terms are aligned with interference signals spanned by two dimensional interference subspaces V_1 and V_4. Subspace V_5 is absent to receiver 1 since the transmitted signals X_4 and X_5 present in V_5 does not reach receiver 1. So, the desired message (a_1 & a_2) for the receiver 1 can be recovered successfully. In the similar manner, all receivers recovers its desired messages within four time slots yielding the symmetric DoF of 1/2. Alignment Non-conflict matrix (A_5) for 5-prime substances is given below in fig.2 (a) which shows that the subspace V_5 is absent to receiver 1 and subspaces V_1, V_2, V_3, V_4 are absent to receiver 2, 3, 4 & 5 respectively.

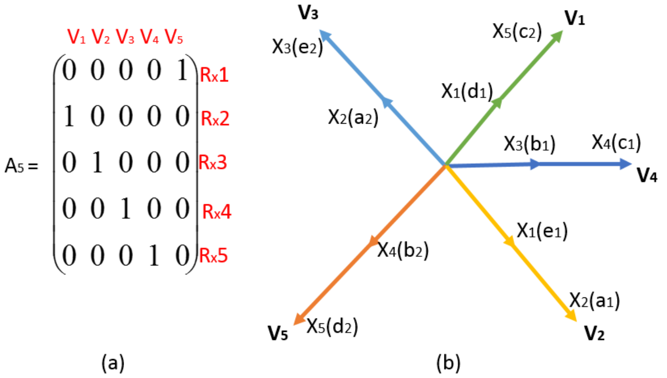


Fig.2. (a) Alignment Non-Conflict matrix for (5, 3) regular cellular network with modulo 3 functionality and (b) its corresponding Interference Alignment Scheme for ($\tau_c \geq 4$)

Now, we consider the above case for the worst case fading channel where τ_c =1. Here we assume that ten time slots are used to send transmitter signals which spans ten dimensional subspace as below

$$X_1 = V_1d_1+V_2d_2+V_4e_1+V_5e_2+V_7d_5+V_8a_5 \qquad (7)$$

$$X_2 = V_3a_1+V_4a_2+V_6e_3+V_7e_4+V_9b_5+V_{10}e_5 \qquad (8)$$

$$X_3 = V_5a_3+V_6a_4+V_8b_1+V_9b_2+V_1c_5+V_2a_5 \qquad (9)$$

$$X_4 = V_7b_3+V_8b_4+V_{10}c_1+V_1c_2+V_3d_5+V_4b_5 \qquad (10)$$

$$X_5 = V_9c_3+V_{10}c_4+V_2d_3+V_3d_4+V_5c_5+V_6e_5 \qquad (11)$$

Where the last two terms in all five transmitter signals (marked in orange) are repeatedly sent twice. For example, we express the received signal at receiver 1 within 10 time slots with $R_1 = \{1, 2, 3\}$, $Y_1 = h_{11}X_1 + h_{12}X_2 + h_{13}X_3 + Z_1$ as

$$y_1(1) = d_1h_{11}(1) + c_5h_{13}(1),\ y_1(2) = d_2h_{11}(2) + a_5h_{13}(2)$$
$$y_1(3) = a_1h_{12}(3),\ y_1(4) = e_1h_{11}(4) + a_2h_{12}(4)$$
$$y_1(5) = e_2h_{11}(5) + a_3h_{13}(5),\ y_1(6) = e_3h_{12}(6) + a_4h_{13}(6)$$
$$y_1(7) = d_5h_{11}(7) + e_4h_{11}(7),\ y_1(8) = a_5h_{11}(8) + b_1h_{13}(8)$$
$$y_1(9) = b_5h_{12}(9) + b_2h_{13}(9),\ y_1(10) = e_5h_{12}(10)$$

Symbols $\{a_1, a_2, a_3, a_4$ & $a_5\}$ can be easily recovered from $\{y_1(2), y_1(3), y_1(4), y_1(5), y_1(6), y_1(8)\}$. The desired symbols a_1 and a_2 are spanned by two dimensional subspace V_3 and V_4 respectively. Symbols a_3, a_4, a_5 & d_5 are spanned by four dimensional subspaces V_5, V_6, V_2 & V_7 respectively. After subtracting the interference, we can recover all the five symbols $\{a_1, a_2, a_3, a_4$ & $a_5\}$ for receiver 1 within 10 time slots yielding DoF of 1/2. In the similar manner, all receivers can decode its desired signals which gives the symmetric DoF of 1/2. Interference Alignment scheme is shown below where the transmitters spans ten dimensional subspaces with τ_c =1 are shown in the below figure.

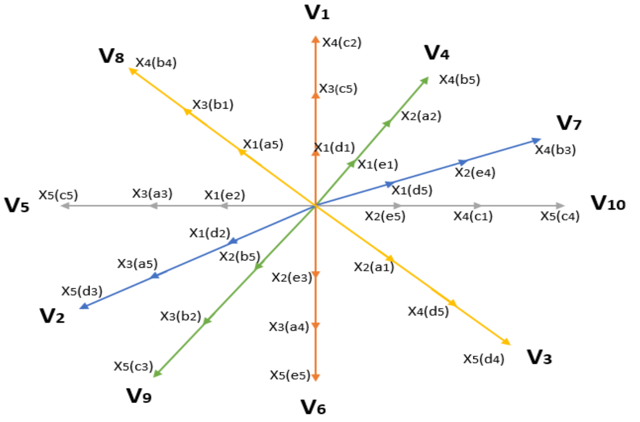
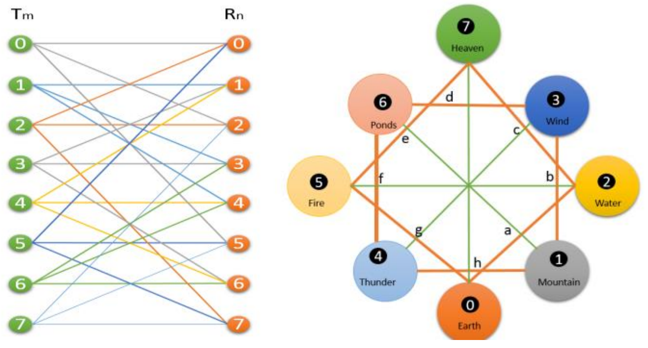


Fig.3: Interference Alignment Scheme for (5, 3) regular cellular network with modulo 3 functionality when $\tau_c = 1$

B. 8 users as 8- Trigram



(a) **(b)**

Fig.4. (a) Network Topology for (8, 3) regular cellular network and (b) its alignment feasibility graph with triangular transmitter cooperation.

Definition 2: Tripartite Graph: A set of graph vertices are disintegrated into three separate sets in a way that no two graph vertices within the same set are adjacent. The interaction between the 8 trigrams uses triangular transmit co-operation between the vertices (for e.g. Vertices 2 & 5 co-operates with each other to help the vertex 0 and vice versa).

A (8, 3) regular network refers to the K-cell network where each receiver will overhear the signals from the transmitter with the same index as well as the signals from the receivers having a symmetric TTC cooperation. For example: In a given triangle {0, 2, 5}, Transmitters 5 & 2 are co-operative to the Receiver 0. The same pattern is applied to all other receivers as each R_n has symmetric cooperation from the two transmitters as well as the transmitter from the same index. Transmitter sets T_m and Receiver sets R_n are obtained from the network topology and they are written as follows.

$T_0=R_0=\{0, 2, 5\}$, $T_1=R_1=\{1, 3, 4\}$, $T_2=R_2=\{2, 0, 7\}$,
$T_3=R_3=\{3, 1, 6\}$, $T_4=R_4=\{4, 1, 6\}$, $T_5=R_5=\{5, 0, 7\}$,
$T_6=R_6=\{6, 3, 4\}$, $T_7=R_7=\{7, 2, 5\}$.

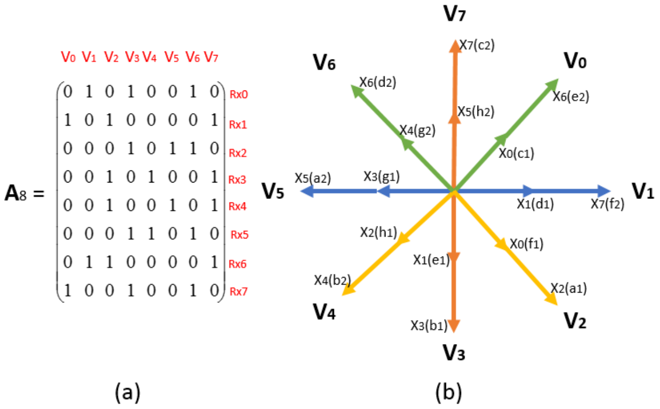
We also choose a, b, c, d, e, f, g & h are the desired messages for the R_n 1 to R_n 8 respectively with the subscript denoting different symbols for the same receiver. These messages are precoded with eight random precoding vectors V0 to V7 after which these signals will be sent by the transmitters within 4 time slots are as follows. The symbols are precoded with eight random vectors denoted by V_1, V_2, V_3, V_4, V_5, V_6, V_7, $V_8 \in C^{3x1}$, where any three vectors are linearly independent covering three dimensional subspace. These symbols will be sent by the transmitters within 3 time slots as below

$X_0=V_0c_1+V_2f_1$; $X_1=V_1d_1+V_3e_1$; $X_2=V_2a_1+V_4h_1$;
$X_3=V_3b_1+V_5g_1$; $X_4=V_4b_2+V_6g_2$; $X_5=V_5a_2+V_7h_2$;
$X_6=V_6d_2+V_0e_2$; $X_7=V_7c_2+V_1f_2$ (12)

Where $X_m \in C^{3x1}$ is the vector of the concatenated transmit signals from transmitter m with each element being the transmitted signal at each corresponding time slot. We consider the channel coherence time as $\tau_c \geq 4$. Interference alignment scheme with the above coherence time for 8-user network is given in fig.5 (b). For example, we express the received signal at receiver 1 within three time slots with
$R_1=\{1, 3, 4\}$ as

$$Y_1 = h_{11}X_1 + h_{13}X_3 + h_{14}X_4 + Z_1 \tag{13}$$
$$= V_3h_{13}b_1 + V_4h_{14}b_2 + V_1h_{11}d_1 + V_3h_{11}e_1 + V_5h_{13}g_1 + V_6h_{14}g_2 + + Z_1$$

Where the first two terms in the above equation carries desired signals b_1 and b_2 spanned by two dimensional interference free subspaces V_3 and V_4 respectively. The next four terms are aligned with interference signals spanned by one dimensional interference subspaces V_5. Remaining Subspaces V_0, V_2, V_7, V_5 & V_6 are absent to receiver 1. Transmitted signals present in V_0, V_2 & V_7 does not reach receiver 1 due to T_1. Transmitter cooperation between X3 and X4 makes the subspaces V5 and V6 absent to receiver 1. So, the desired message (b_1 & b_2) for the receiver 1 can be recovered successfully. In the similar manner, all receivers recovers its desired messages within three time slots yielding the symmetric DoF of 2/3. Alignment Non-conflict matrix (A_8) for 8-trigram is given below in fig.5 (a) which shows that the subspaces V_0, V_2 & V_7 are absent to receiver 1.



$$A_8 = \begin{array}{c|c} V_0\ V_1\ V_2\ V_3\ V_4\ V_5\ V_6\ V_7 & \\ \begin{pmatrix} 0 & 1 & 0 & 1 & 0 & 0 & 1 & 0 \\ 1 & 0 & 1 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 & 0 & 1 & 1 & 0 \\ 0 & 0 & 1 & 0 & 1 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 & 0 & 1 & 0 & 1 \\ 0 & 0 & 0 & 1 & 1 & 0 & 1 & 0 \\ 0 & 1 & 1 & 0 & 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 1 & 0 & 0 & 1 & 0 \end{pmatrix} & \begin{array}{l} Rx0 \\ Rx1 \\ Rx2 \\ Rx3 \\ Rx4 \\ Rx5 \\ Rx6 \\ Rx7 \end{array} \end{array}$$

(a)

(b)

Fig.5. (a) Alignment Non-Conflict matrix for (8, 3) regular cellular network with triangular transmitter cooperation and (b) its corresponding Interference Alignment Scheme for ($\tau_c \geq$ 4)

We now consider the above case for the worst case fading channel where τ_c =1. Here we assume that sixteen time slots are used to send transmitter signals which spans sixteen dimensional subspaces as below

$$X_0= V_0c_1+V_1c_2+V_4f_1+V_5f_2+V_8a_5+V_9f_5 \tag{14}$$

$$X_1= V_2d_1+V_3d_2+V_6e_1+V_7e_2+V_{10}e_5+V_{11}b_5 \tag{15}$$

$$X_2= V_8a_1+V_9a_2+V_{12}h_1+V_{13}h_2+V_0c_5+V_1h_5 \tag{16}$$

$$X_3= V_{10}b_1+V_{11}b_2+V_{14}g_1+V_{15}g_2+V_2d_5+V_3g_5 \tag{17}$$

$$X_4= V_0b_3+V_1b_4+V_8g_3+V_9g_4+V_{12}e_5+V_{13}b_5 \tag{18}$$

$$X_5= V_2a_3+V_3a_4+V_{10}h_3+V_{11}h_4+V_{14}f_5+V_{15}a_5 \tag{19}$$

$$X_6= V_4d_3+V_5d_4+V_{12}e_3+V_{13}e_4+V_6g_5+V_7d_5 \tag{20}$$

$$X_7= V_6c_3+V_7c_4+V_{14}f_3+V_{15}f_4+V_4c_5+V_5h_5 \tag{21}$$

For example, we express the received signal at receiver 1 within sixteen time slots with $R_1=\{1, 3, 4\}$ as given below

$$Y_1 = h_{11}X_1 + h_{13}X_3 + h_{14}X_4 + Z_1$$

$$\begin{aligned} &y_1(1) = b_3h_{14}(1), y_1(2) = b_4h_{14}(2), \\ &y_1(3) = d_1h_{11}(3) + d_5h_{13}(3), y_1(4) = d_2h_{11}(4) + g_5h_{13}(4) \\ &y_1(7) = e_1h_{11}(7), y_1(8) = e_2h_{11}(8), y_1(9) = g_3h_{14}(9) \\ &y_1(10) = g_4h_{14}(10), y_1(11) = e_5h_{11}(11) + b_1h_{13}(11) \\ &y_1(12) = b_5h_{11}(12) + b_2h_{13}(12), y_1(13) = e_5h_{14}(13) \\ &y_1(14) = b_5h_{14}(14), y_1(15) = g_1h_{13}(15), y_1(16) = g_2h_{13}(16) \end{aligned}$$

Symbols {b_1, b_2, b_3, b_4 & b_5} can be easily recovered from {$y_1(11)$, $y_1(12)$, $y_1(1)$, $y_1(2)$, $y_1(14)$}. Desired symbols b_1 and b_2 are spanned by two dimensional subspace V_{10} and V_{11} respectively. Symbols b_3, b_4, b_5 & e_5 are spanned by four dimensional subspaces V_0, V_1, V_{13} & V_{12} respectively. After subtracting the interference, we can recover all the five symbols {b_1, b_2, b_3, b_4 & b_5} for receiver 1 within 8 time slots yielding DoF close to 2/3. In the similar manner, all receivers can decode its desired signals which gives the symmetric DoF of 2/3 which is similar to the slow fading channel with channel coherence time $\tau_c \geq 4$. Triangular transmitter cooperation algorithm is given in appendix for further understanding in achieving the symmetric DoF for 8 user network topology. Interference Alignment scheme is shown below where the transmitters spans sixteen dimensional subspaces with $\tau_c = 1$ are shown in the below figure.

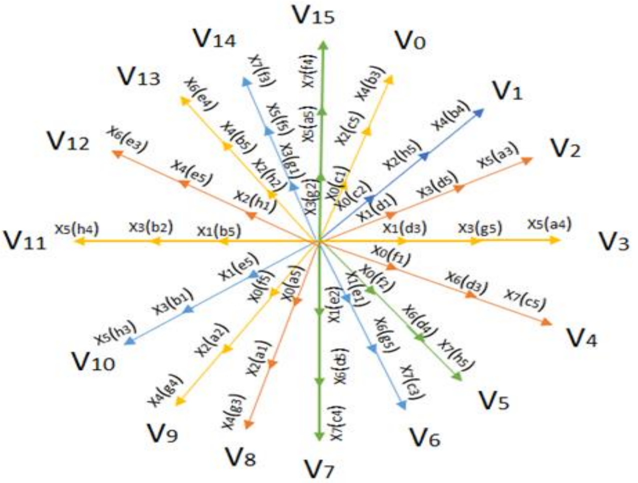


Fig.6: Interference Alignment Scheme for (8, 3) regular cellular network with triangular transmitter cooperation when $\tau_c = 1$

IV. CONCLUSION AND FUTURE WORKS

In this paper, topological interference management problem with transmitter cooperation is considered where we provide the characterization of the DoF region for 5-prime substances and 8-trigrams. Modulo 3 functionality in 5 user network topology makes it easier for the transmitter cooperation to achieve the DoF of 1/2 with the help of the interference alignment schemes. Another proposed model of 8 user networks has an interesting advantage to its topology where two symmetric transmitters cooperate with each other to achieve the improved symmetric DoF of 2/3 compared to 5 user network topology. Eight trigram structure can also be applied to 3D hyper cubes which will have greater advantages to wireless networks due to its numerous applications.

APPENDIX

Triangular transmitter cooperation introduced in 8- trigrams improves the feasible symmetric DoF. We have proposed here a generalized algorithm for 8 user network topology which follows triangular transmit cooperation to achieve the symmetric DoF.

Algorithm 1: Triangular Transmitter Cooperation (TTC) algorithm for 8 user network topology

Step 1: Initialize the transmitter sets and receiver sets for a receiver n from the given network topology i.e.
$T_m = R_n = \{i, j, k\}, \forall\, m=n$.

Step 2: Find the missing transmitter signals which does not belong to receiver n. i.e. T_m^C # {i, j, k}

Step 3: If R_n = {i, j, k}, then (i) find interference free (IF) subspaces carrying desired signals denoted by V_{IF}
(ii) Find subspaces carrying aligned interference (AI) signals denoted by V_{AI} and go to step 4

Else if $R_n = T_m^C$, then find the subspaces carrying only transmitter signals that are not intended (NI) to R_n & make it zero i.e. V_{NI}= {0}

Step 4: Find the subspaces from V_{IF} that carries the same message signal transmitted by T_m (where j & k are symmetric to each other and cooperates with 'i' to form a triangular transmit cooperation and the subspace formed through TTC are denoted by V_{TTC}) and make V_{TTC} zero.

Step 5: So the desired messages reaches receiver n through the remaining subspaces to attain feasible DoF. **Repeat the above steps to all the receivers achieving symmetric DoF**.

ACKNOWLEDGMENT

This work has been supported by the MEST, 2015 R1A2A1A 05000977, NRF, BK, Korea.

REFERENCES

[1] Fritjof Capra, "The Tao of Physics: An Exploration of the parallels between modern physics and Eastern mysticism", Philosophy East and West, Vol. 28, pp. 387-39, Jul 1978.

[2] A. Tehrani, A.Dimakis and M.neely,"Bipartite index coding," in Information Theory Proceedings (ISIT), pp.2246-2250, July 2012.

[3] X. Yi and D. Gesbert, "Topological interference management with transmitter cooperation," in Information Theory (ISIT), pp.846-850, July 2014.

[4] S. Jafar, "Topologial interference management through index coding," in Information Theory, IEEE Transactions on , vol.60, no.1, pp.529-568, Jan. 2014.

[5] N.Naderializadeh and A.S.Avestimehr, " Interference networks with no CSIT: Impact of topology," in Information Theory Proceedings (ISIT), 2013 IEEE International Symposium on , pp.394-398, July 2013.

[6] S. Jafar, "Elements of cellular bilnd interference alignment-aligned frequnecy reuse, wireless index coding and interference diversity," arXiv:1203.2384v1 [cs.IT], Mar 2012.