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Maximization Mechanism for Spectrum and Energy Efficiencies in Wireless Networks using Device to Device Communications

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Abstract:
A linear optimization method along with power control effectively enhances the spectrum and energy efficiencies in D2D networks. In this paper, we propose a linear program for assigning bandwidth to the links based on systems demands, heterogeneity, traffic insertion patterns and network topology. Also, we propose a power control mechanism derived from M-matrix theory to complement the achieved spectrum and energy efficiencies. By the obtained simulation results, it is shown that the proposed mechanisms enhance the spectrum and energy efficiencies by 25% compared to existing methods.

Keywords: *5G networks, energy efficiency, linear program, D2D communications, spectrum efficiency, M- Matrices.*

I. INTRODUCTION

Wireless networks provide various multimedia applications to numerous users [1], with many devices contending for accessibility over sparser bandwidth. In order to reduce the power consumption due to availing multiple services, we use D2D communications. D2D and IOT networks use battery devices i.e., low power devices, so there is need for utilizing every unit of energy to transmit the information (i.e., Energy Efficiency). D2D communications is supported in the 5G and DSA networks [2] through IOT, which in turn, is used in many systems that provides applications like measuring the quality of indoor air and ventilation rate [3], military, management of heat and electricity in smart cities. D2D communications allows proximity devices to communicate via direct link i.e., without any data transversal through the base station, thereby reducing the power consumption. Secondary networks like D2D, M2M, use spectrum sensing to detect the white spaces (that are unoccupied by the primary users) and utilizes the spectrum if primary user is inactive.

The proposed method contributes maximization mechanisms for enhancing the spectrum and energy efficiencies in the wireless networks using D2D communications. We propose a linear program for improving spectrum efficiency based on link demands, heterogeneity, and arrangement of nodes in the network and traffic insertion patterns. We calculate the limits for the achievable spectrum efficiency.

We use power control mechanism (based on M-Matrix theory) to provide 25% of improvement in both spectrum and energy efficiencies when compared to existing mechanisms that considers uniform traffic. In the sections II & III we discuss existing mechanisms and proposed model. Simulation results are depicted in section IV and conclusions are given in section V.

II. EXISTING METHOD

Earlier, graph coloring methods were used for assigning channels to every device in the network, these techniques allows each node to acquire single color (channel) and disallows nodes to contend for new channels resulting in the underutilization of resources. A distributed algorithm called Maximum Spectral Packing mechanism [4] enables multi-color assignment.

A. MASPECT Approach:

Consider a secondary user network as shown in the Fig.1. In the below modeled graph, node B can acquire the color of node C or D because they are separated by a distance, d_{min}.

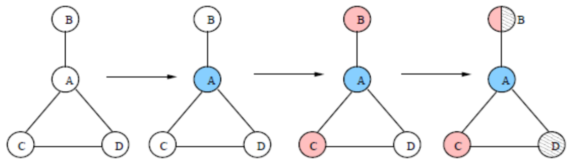

Fig.1.GraphIteration 1Iteration 2Iteration 3

By using the centralized method, node B obtains only one color that is either color of node C or D, where as MASPECT allows multi-channel assignment.

In the first iteration, node A obtains the color 1 (i.e., channel is assigned to node A) as it is having the highest degree value. If two nodes (here C and D) are having same degree, then, the node with small random back off will acquire the color first. In the second iteration node B and node C obtains color2. At this point, all neighbors of B has obtained color but not by links connected to A. In the next iteration color3 is assigned to node D and B. New nodes can get added and existing can leave easily without affecting the algorithm functionality. By considering local topology this algorithm provides an enhancement of 20% in spectrum utilization.

B. Probabilistic Heuristic (PMASPECT):

If a system with a uniform traffic is considered then all nodes will have equal degree, thereby competing for same color. To resolve contention, each node maintains a sub graph that contains local topology and rank of each node in it. Based on this information, PMASPECT reduces the contention probability and terminates in very less iterations compared to MASPECT for channel allocation.

This algorithm reduces the delay for accessing the channels initially and provides an improvement in magnitude up to two orders.

III. PROPOSED METHOD

Consider a network of D2D devices having five nodes, as shown in the Figure 2(a). Two vertices that have an edge between them can share a common bandwidth. All devices broadcasts topological information and link demands over control channel. The network model can be redrawn as the edge graph shown in Fig. 2(b)

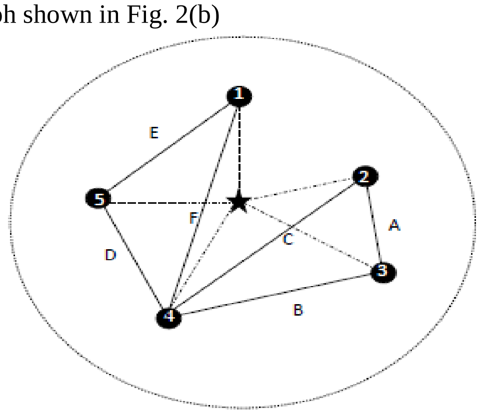

Fig. 2(a) Network Graph, Ḡ

Let Ḡ (Ṽ, Ẽ) represents the original graph of D2D network, where Ṽ represents the set of nodes and Ẽ represents the group of neighboring links.Maximal Independent Sets [5] contains information about vertices that can share common bandwidth without interference. The matrix $M_{IS}= [m_{ij}]$, $1\leq i \leq N$, $1\leq j \leq N$, provides the information regarding vertices in MIS.

$$m_{ij}= \begin{cases} 1 & vertex\ i\ belongs\ to\ MISj, \\ 0 & otherwise \end{cases} \quad (1)$$

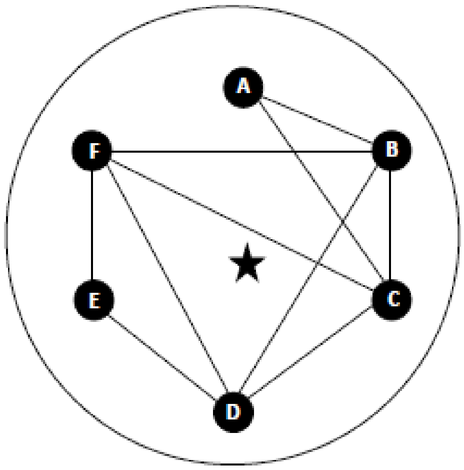

Fig. 2(b) Edge Graph

A. Spectrum Efficiency

Let the desired spectrum efficiency be **η**, the total data supported by all vertices in G is B, gi is fraction of traffic inserted by link i in graph, G. Let X_j represents the portion of bandwidth [6] assigned to all nodes in MISJ. Adequate amount of B.W should be assigned to all nodes in G, in order to support **η**. This leads to the limitation,

$$\sum_{j=1}^{M} X_j m_{ij} \geq B\eta g_i;\ 1 \leq i \leq N \quad (2)$$

To avoid interference, each MIS is assigned with non-adjacent segments of bandwidth, due to which X_j, cannot exceed the total bandwidth, B i.e.,

$$\sum_{j=1}^{M} X_j = B \quad (3)$$

By considering the link demands, objective function can be written as,

$$\frac{1}{B}\sum_{i=1}^{N} \min(B\eta g_i, d_i) \quad (4)$$

$$\text{Let } \bar{Y}j \triangleq \frac{X_j}{B}, \forall j \quad (5)$$

By dividing equations (2) and (3) with B, we get two more limitations, (6) and (7).

$$\sum_{j=1}^{M} Y_j\, m_{ij} \geq \eta g_i;\ for\ all\ i \quad (6)$$

$$\sum_{j=1}^{M} Yj = 1 \quad (7)$$

By considering limitations above, we maximize the objective function in equation (4). Now, we discuss the properties of S (**η**) as follows:

November-December 2019
ISSN: 0193-4120 Page No. 6342 - 6347

Let $h_i=\frac{d_i}{g_i}$be the sequence, then from equation (4), we get,

$$S(\eta) = \frac{1}{B}\sum_{i=1}^{N} d_i + \eta \sum_{i=1}^{N} g_i \qquad (8)$$

$\boldsymbol{\eta}\in \left[\frac{h_{k-1}}{B}, \frac{h_k}{B}\right)$which indicates S ($\boldsymbol{\eta}$) is non-decreasing and piece wise linear function of$\boldsymbol{\eta}$.

For any value of K,S (n_k^-) = S (n_k^+)(9)

It shows S ($\boldsymbol{\eta}$) is continuous

Consider $\chi > \eta$, where $\boldsymbol{\eta}<\frac{h_{k-1}}{B}$ and $\chi > \frac{h_k}{B}$, then

$S'(\boldsymbol{\eta}) \geq S'(\chi)$, also $S''(\boldsymbol{\eta}) \leq 0$(10)

This proves the property of concavity.

We now extract the bounds for S($\boldsymbol{\eta}$) i.e., achievable spectrum efficiency. Let the maximum value of $\boldsymbol{\eta}$, be $\boldsymbol{\eta}_0= h_i$, $B\eta_0 g_i < d_{i}$ $\forall i$ then $\forall \boldsymbol{\eta} \leq \boldsymbol{\eta}_0$, $S(\eta) = \eta$.

If $\boldsymbol{\eta} < \boldsymbol{\eta}_0$, then

$S(\eta) = \frac{1}{B}\sum_{i=1}^{N} \eta B g_i = \eta \sum_{i=1}^{N} g_i = \eta;$

If $\boldsymbol{\eta}_0 \geq 1$ i.e., no spectrum reuse is considered then $Y_j= \boldsymbol{\eta} g_i$, ∀i and $S(\eta) = \eta = \sum_{j=1}^{M} Y_j = 1$.

If$\eta_0 \geq \hat{\eta}, Z_j \triangleq \frac{Y_j}{\eta}$ then $\frac{1}{\hat{\eta}}$ is the solution to min$\sum_{j=1}^{M} Y_j$. Dividing the equations (6) and (7) by η yields,

$$\sum_{j=1}^{M} Z_j mij \geq g_i;\ 1 \leq j \leq M \qquad (11)$$

And $\sum_{j=1}^{M} Z_j = \frac{1}{\eta};\ 1 \leq i \leq N$

Above equations proves that the slope of achievable spectrum efficiency is 1 and decreases further with increase of $\boldsymbol{\eta}$.

For all values of $\eta > \tilde{\eta}$, when $\eta \geq \max\frac{d_i}{B}$; $\forall\ 1 \leq i \leq N$ is satisfied subject to limitations (6) and (7), then

$$S(\eta) = \sum_{i=1}^{N} \frac{d_i}{B} (12)$$

Equation (12) indicates that after certain value of threshold, S($\boldsymbol{\eta}$) depends only on the system demands.

If $\eta \geq \eta_{max}$ then $S(\eta) \leq MIS_{max}$ subject to constraint,

$$\sum_{j=1}^{M} Y_j\ mij \leq \eta g_i; \qquad (13)$$

$$Also,\ S(\eta) = \sum_{j=1}^{N} Y_j\ MISj;\ \forall i \qquad (14)$$

S($\boldsymbol{\eta}$) is finite and limited by MIS_{max}. In the above analysis of S($\boldsymbol{\eta}$) we have considered that all devices communicate at maximum power.

B. Energy Efficiency

To enhance the energy efficiency, all nodes in the networks should use minimum power for transmission, which in turn, increases the neighboring links that can reuse the same bandwidth. Concurrent transmissions results in interference, there by reduction in the signal quality. So we introduce a power control mechanism [7] that allows bandwidth reuse and energy conservation without affecting the quality of information. Consider a device u, is transmitting signal to device v, then following assumptions needs to be considered to describe control mechanism.

The system has a total background noise $B_v N_0$, Where N_0 is power spectral density and $B_v$is available bandwidth.

Noise cancellation gain G_{uv} ,at the receiver.

The transmission link between device u and v needs to meet minimum SINR, ϵ_{uv} (Signal-to-interference ratio).

Power loss during the transmission i.e., h_{uv}(or channel gain)

Consider a device v, is receiving signals from L devices that are using same bandwidth concurrently i.e., v receives data from u ∈ (1, 2…..L) and u' ∈ (1,2….L) ; u` ≠ u, Then SINR at V is written as

$$\Gamma_{uv} = \frac{P_u h_{uv} G_u}{\sum_{u' \neq u} P_{u'} h_{u'v} + N_0 B_v}(15)$$

The energy efficiency can be improved by solving

$$min \sum_u P_u,(16)$$

By applying constraints,

$$\Gamma_{uv} = €_{uv}, \forall\, u \qquad (17)$$

$$0 \leq P_u \leq P_{max}^{(u)},\ \forall\, u \qquad (18)$$

The equation (15) can be written as

$$\frac{P_u h_{uv} G_{uv}}{€uv} - \sum_{u' \neq u} P_{u'} h_{u'v} = N_0 B_v (19)$$

The matrix form of above equation can be written as,

$$H_p = N_0 b \rightarrow p = H^{-1} b(20)$$

$$H = \begin{pmatrix} \frac{G_{1v}h_{1v}}{€1v} & -h_{2v} \cdots & -h_{Lv} \\ -h_{1v} & \frac{G_{2v}h_{2v}}{€Lv} \cdots & -h_{Lv} \\ \vdots & \vdots & \vdots \\ -h_{1v} & -h_{2v} \cdots & \frac{G_{Lv}h_{Lv}}{€Lv} \end{pmatrix}$$

Where, H is an M-Matrix [8], c, d^T are positive vectors

$$P=\begin{pmatrix} P_1 \\ P_2 \\ P_3 \\ \vdots \\ P_L \end{pmatrix} b=N_0B\begin{pmatrix} 1 \\ 1 \\ 1 \\ \vdots \\ 1 \end{pmatrix}(21)$$

D is non negative diagonal matrix

$$H=D-cd^T,\ D= \operatorname{diag}\left(huv\left[\frac{G_{Lv}h_{Lv}}{€Lv} + 1\right]\right)(22)$$

For all, 1≤ u ≤ L

$$C = \begin{pmatrix} 1 \\ 1 \\ 1 \\ 1 \end{pmatrix}, d^T=\begin{pmatrix} h1v \\ h2v \\ \vdots \\ hLv \end{pmatrix}^{-1}$$

The equation $Hp=N_o b \Rightarrow P=H^{-1}$ attains a feasible solution [9] i.e. $P_u \geq 0$ where inverse of H has all positive elements i.e., *M*-matrix, only if it satisfies below condition

$$\sum_{u=1}^{L} \left(1 + \frac{Guv}{\epsilon_{uv}}\right)^{-1} < 1 \qquad (23)$$

Applying Sherman Morrison formula [10] to (22), we get,

$$H^{-1} = D^{-1} + \frac{D^{-1}cd^T D^{-1}}{1-cd^T D^{-1}}(24)$$

Also, $1- d^T D^{-1} c>0$

Equation (23) ensures that $P_u \geq 0$, $\forall u$, to be satisfied but not considers $P_u \leq P_{max}^{(u)}$

Equation (23) would be necessary and adequate if $P_{max}^{(u)} \rightarrow \infty, \forall n$.

IV. SIMULATION RESULTS

We consider a network of 30 D2D devices [11] and a bandwidth of 50MHZ, and then we generate random graphs [12] of densities (GD) 0.2, 0.5 & 0.8. We consider three different traffic insertion patterns. The scenarios are:

(1) Uniform Traffic
(2) More traffic at spare nodes
(3) More traffic at dense nodes

The proposed method is compared with the previous mechanisms in [4].

Fig (3a) we can observe that achieved spectrum efficiency is more in the scenarios of uniform traffic and more traffic in sparse nodes. At some value of **η** (here **η**= 12.5 bits/H2), irrespective of varying traffic, S(**η**) will saturate in case of proposed method, where as monotonically increasing for existing mechanisms.

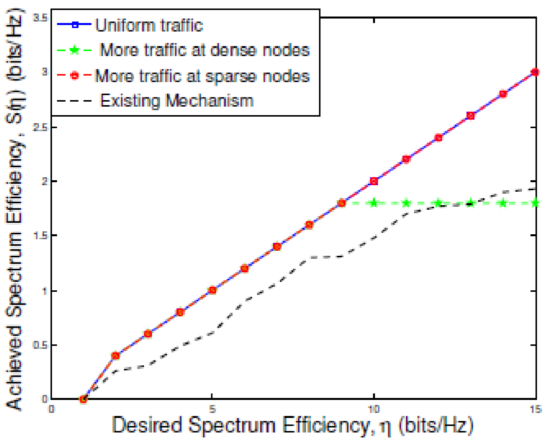

Fig.3a. Sparse graph (GD=0.2) depicting spectrum efficiency for all traffic patterns.

Fig (3b), For graph density 0.5, scenario (iii) shows an improvement of 20% of S(**η**) compared to existing methods and strength is increased by two orders for scenario (i) & (ii).

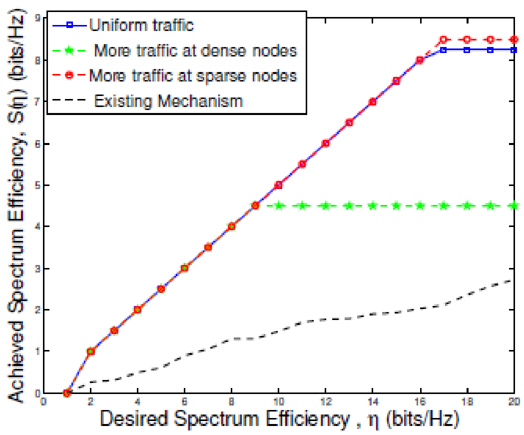

Fig.3b. Moderately Sparse (GD=0.5) graph depicting spectrum efficiency for all traffic patterns

In Fig (3c), more traffic at crowded nodes shows 50% of improvement over previous technique while, in scenario (i) and (ii), the magnitude is improved by four orders compared to existing mechanism.

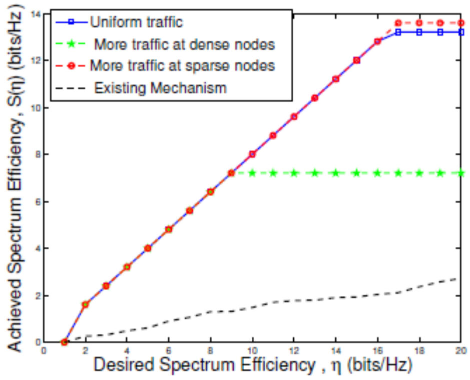

Fig.3c. Dense graph (GD=0.8) depicting spectrum efficiency for all traffic patterns

In fig (4) we observe spectrum efficiency, for different values of transmission power. We consider the value of **η** as constant. Increase of transmission power results in addition of new nodes to the network, thereby reducing the chances of reuse. This result in monotonically decreasing values of spectrum efficiency in all scenarios as depicted in Fig. (4a)(4b)(4c).

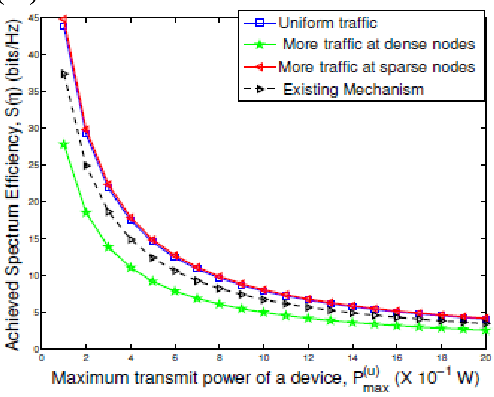

Fig.4a. Sparse graph (GD=0.2) depicting spectrum efficiency with respect to varying transmission powers for all traffic patterns.

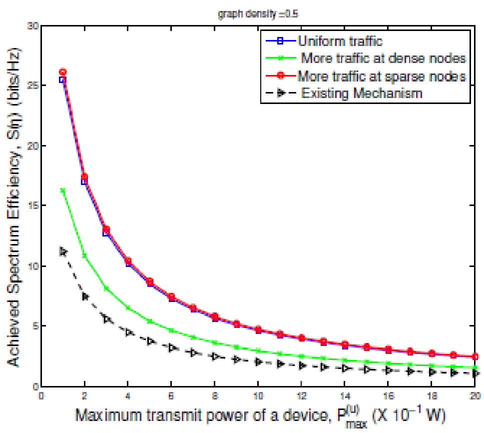

Fig.4b. Moderately graph (GD=0.5) depicting spectrum efficiency with respect to varying transmission powers for all traffic patterns

November-December 2019
ISSN: 0193-4120 Page No. 6342 - 6347

Fig. (5) We choose P_u^{max}= 2W and an Okumara-hata model [13] is used to derive h_{uv}'s. By varying **η** values, we observe the energy efficiency. For graph density=0.2, scenario (i) and (ii) shows25% of improvement in power conservation as depicted in fig 5(a).

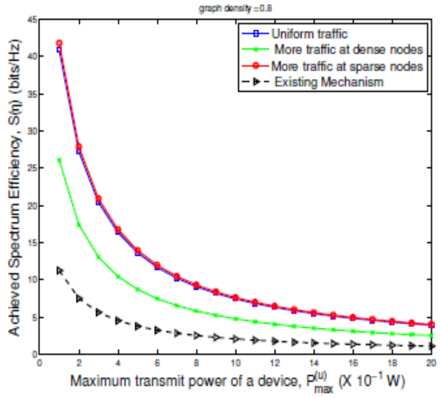

Fig.4c. Dense graph (GD=0.8) depicting spectrum efficiency with respect to varying transmission powers for all traffic patterns.

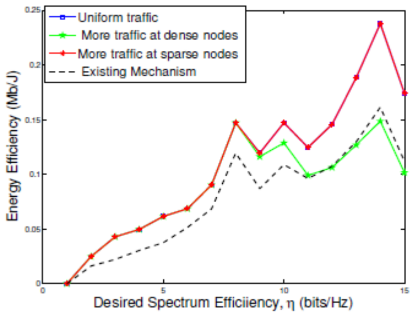

Fig.5a. Sparse graph (GD=0.2) depicting Energy efficiency with respect to varying values of spectrum efficiency for all traffic patterns.

In fig (5b) and (5c), we can observe that, compared to existing mechanism, moderately dense and dense graphs for scenarios (i) and (ii) shows 4 and 5 orders of improvement in strength of energy efficiency respectively.

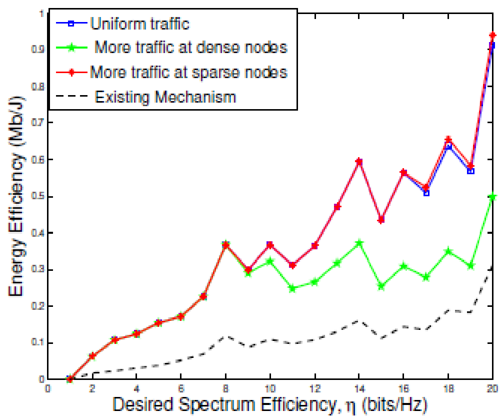

Fig.5b. Moderately sparse graph (GD=0.5) depicting Energy efficiency with respect to varying values of spectrum efficiency for all traffic patterns.

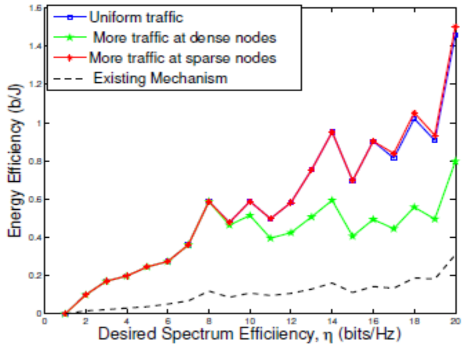

Fig.5.c Dense graph (GD=0.8) depicting Energy efficiency with respect to varying values of spectrum efficiency for all traffic patterns.

Figure. (6)We choose **η**=14. Due to constraint (18), we can observe that increase in transmit power results in enhancement of energy efficiency in all scenarios as shown in Fig. 6(a), 6(b), 6(c).

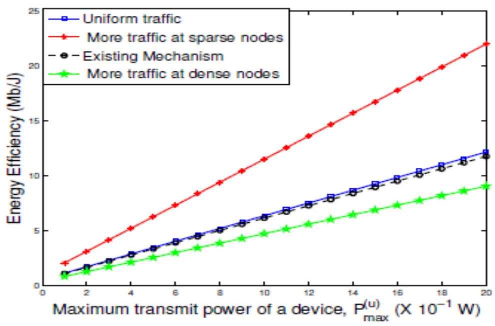

Fig.6.a Sparse graph (GD=0.2) depicting Energy efficiency with respect to varying transmit powers for all traffic patterns.

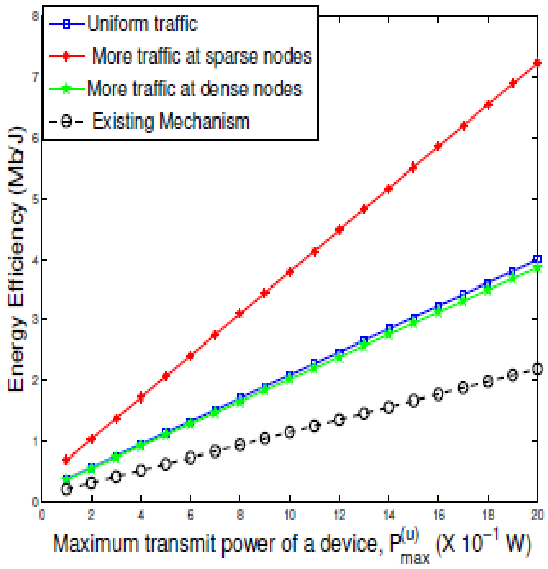

Fig.6.b Moderately Sparse graph (GD=0.5) depicting Energy efficiency with respect to varying transmit powers for all traffic patterns.

TEST Engineering & Management

November-December 2019
ISSN: 0193-4120 Page No. 6342 - 6347

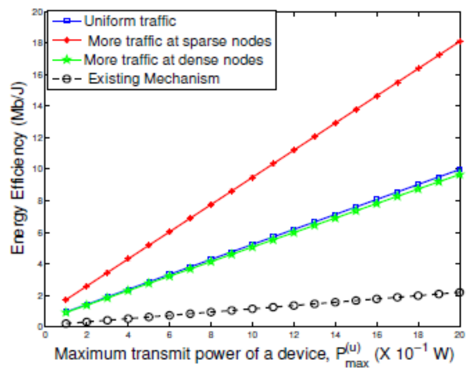

Fig.6.c Dense graph (GD=0.8) depicting Energy efficiency with respect to varying transmit powers for all traffic patterns.

In figure (7) we can observe the performance of spectrum efficiency with and without control mechanisms. In Fig (7a) and (7b) for graph densities, 0.5 and 0.8, power control mechanism enhances achieved spectrum efficiency.

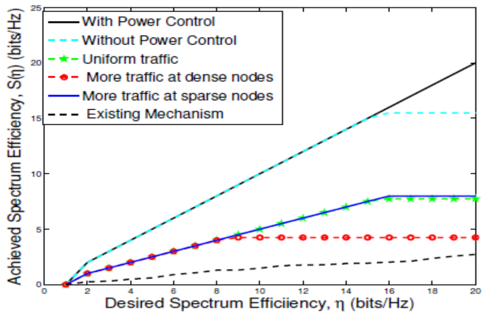

Fig.7.a Moderately Sparse graph (GD=0.5), depicting the effect of power control mechanism on Energy efficiency, thereby on spectrum efficiency for all traffic patterns.

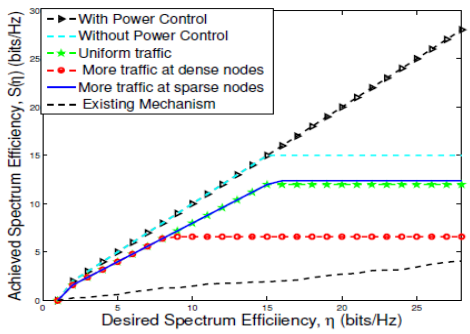

Fig.7.bDense graph (GD=0.8), depicting the effect of power control mechanism on Energy efficiency, thereby on spectrum efficiency for all traffic patterns.

V. CONCLUSION

We proposed a linear optimization along with power control for enhancing the spectrum and energy efficiency by considering link demands, heterogeneity and traffic insertion patterns. Simulation results indicate that the proposed method shows an improvement of 25% in spectrum and energy efficiencies. Future work includes improvement of overall system security by enhancing the proposed method.

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