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Joint Spectrum and Energy Efficiency in Device-to-Device Communication Enabled Wireless Networks

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Abstract

This paper presents a joint spectrum and energy efficiency maximization mechanism for device to device (D2D) communication enabled wireless networks. Most approaches in the literature, fail to take into account link heterogeneity in terms of their demands and the traffic they inject into the network. This paper presents a linear optimization formulation to allocate bandwidth to links, not only based on network topology, but also based on traffic injection patterns of devices and link demands. We derive bounds on the achievable spectrum efficiency. The achieved spectrum efficiency and energy efficiency are further enhanced by deploying power control using M− matrix theory. The proposed approach is shown to provide an improvement between 25% to up to 4 orders of magnitude in spectrum efficiency and between 25% to up to 5 orders of magnitude in energy efficiency compared to existing mechanisms, depending on the network topology and traffic injection patterns of the nodes.

Keywords: spectrum efficiency, energy efficiency, traffic injection patterns

1. INTRODUCTION

Next generation 5G wireless and dynamic spectrum access (DSA) networks provide multiple types of services to a large number of users [1], with many devices competing for a limited available bandwidth [2]. Also, multiple services may result in large energy consumption. In order to support energy conservation, Device-to-Device (D2D) communication is supported in 5G [3], [4] and DSA networks [5], [6], where in, direct communication between two mobile users is possible without data flow into a centralized base station. D2D communications is widely applied in networks using Internet of Things [7], which, in turn, is deployed in a variety of systems including sensor networks [8], air quality systems[9], emergency services [10], health care systems, smart cities, water quality measurements, smart grids, security systems and military environments. Since most D2D networks use low power devices, energy efficiency is a very important requirement. Further, these devices may be placed in a hostile environment, where coverage and available bandwidth may be very poor. This makes joint spectrum and energy efficiency mechanisms an indispensable mandate for D2D communications in 5G networks.

Spectrum efficiency is defined as the amount of information per unit available bandwidth. Most approaches to spectrum efficiency consider homogeneous traffic requirements for all links. As an example, consider the network shown in Fig.1 (a) and its corresponding "link graph" in Fig. 1 (b). Every vertex in the link graph is a link in the original network and two vertices in the link graph share an edge if the corresponding links share a common sensor or device in the original network. Using traditional graph coloring methods, a total of 3 channels are allocated (assuming all nodes in the link graph generate equal amount of traffic. Individually, all nodes obtain one channel. Using an improved mechanism, node A obtains 2 channels and nodes B, C, D and E obtain one channel each. However, if it is turn out that the

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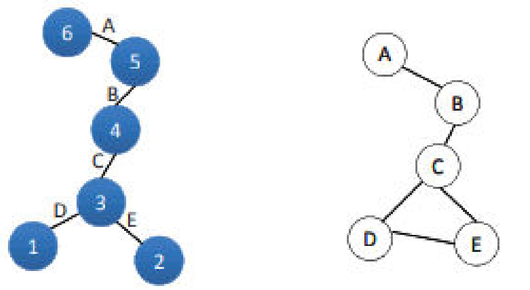
node C (i.e., link (3, 4) in Fig. 1 (a)) is going to generate most of the traffic, then it would be more efficient to allocate more channels to node C even though the algorithm in literature applied to this topology suggests best use of spectrum when more channels are assigned to node A.



(a) An Example Sensor Network

(b) The Corresponding Link Graph

Fig. 1. An example network (Fig. 1 (a)) and it's corresponding "link graph" (Fig. 1 (b)). Every vertex in the link graph is a link in the original network and two vertices in the link graph share an edge if the corresponding links share a common sensor or device in the original network.

OBJECTIVE:

To provide a mechanism to maximize achievedspectrum and energy efficiency taking into account, (*i*) thepower/energy limitations of every device, (*ii*) the limitedavailability of bandwidth in the system, (*iii*) the traffic injectedby each device (and in turn, on each link) and (*iv*) the demands of system on individual links.

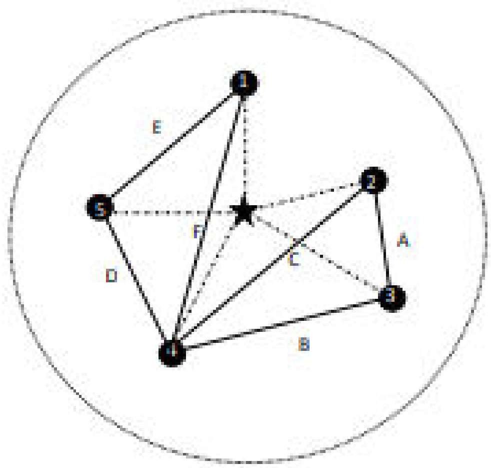
2.SYSTEM MODEL

2.1 PROBLEM DEFINITION

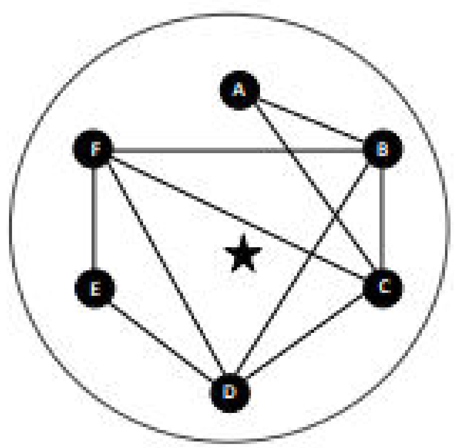
Consider a typical D−node D2D network as shown in Fig. 2(a) (in the figure, the specific case of D = 5 is shown). Each node is a D2D device and communicates with its onehop neighbors (i.e., nodes that can send and receive signals from the concerned node by possibly transmitting at maximum power1). Two one-hop neighbors are said to share a link between them or have an edge between them. The system has a centralized controller (which may either be a base station, or a relay node that can connect to all local devices). All nodes can communicate with the centralized controller directly using a separate pilot or control channel [44]. The system has limited bandwidth available and all pairs of communicating nodes must share the available bandwidth. Since communication between any pair of nodes is equivalent to the communication along the link or edge between the corresponding nodes, all bandwidth must be shared by all the links.

Nodes 1, 2, · · · , 5 are devices that can communicate with the centralized controller marked by ? and with each other if they have an edge or a link between them. An edge or link between two devices indicates that the two devices are one-hop neighbors. All nodes can communicate their neighbor list and demands to the centralized controller. The centralized controller can estimate or compute the traffic patterns of the individual devices from the device type, or from the past information about the bandwidth requests made by the device. The corresponding link or edge graph, G, of the network is shown in Fig. 2(b).

Therefore, a D2D network is also represented by its link graph or edge graph, where in, each vertex in the edge graph represents a link in the original network and two vertices in the edge-graph have an edge between them if the corresponding links share a common node in the original network. As an illustrative example, the link (or edge) graph for the D2D network in Fig. 2(a) is depicted in Fig. 2(b). Each node injects a different amount of traffic into the network. This depends on the device type. As an example, in an air quality monitoring system, the sensor that measures the amount of sulfur dioxide, ozone and nitrous oxides may inject more traffic than another sensor that measures the levels of ozone alone. The amount of traffic injected by a node, in turn, affects the amount of traffic on all the links incident on the node. For instance, in Fig. 2(a), let node 4 generate 40% of the system traffic and node 3 generate 20% of the total system traffic (which the centralized controller can know based on the device type [45]).



(a) An example D2D Network, G˜



(b) Corresponding Link Graph, G

Fig. 2. An graph representation, G˜, of an example D2D network topology (Fig. 2(a)).

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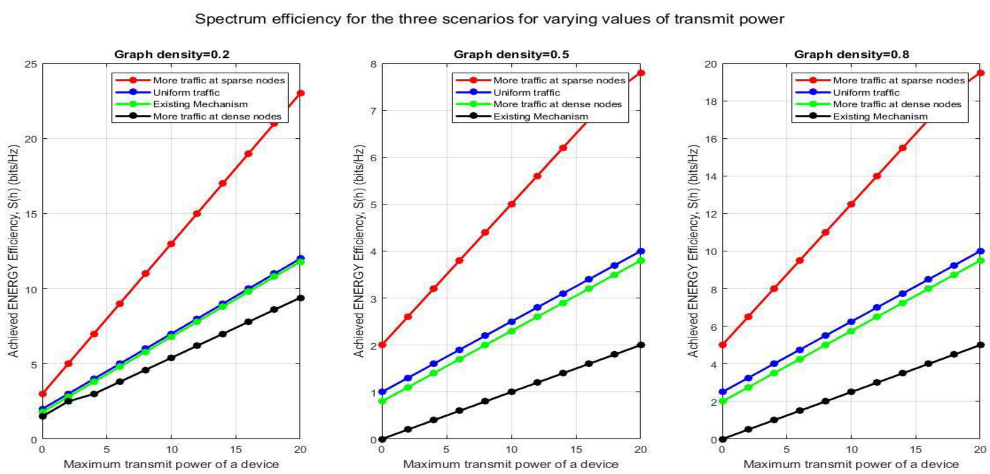
A. Spectrum Efficiency

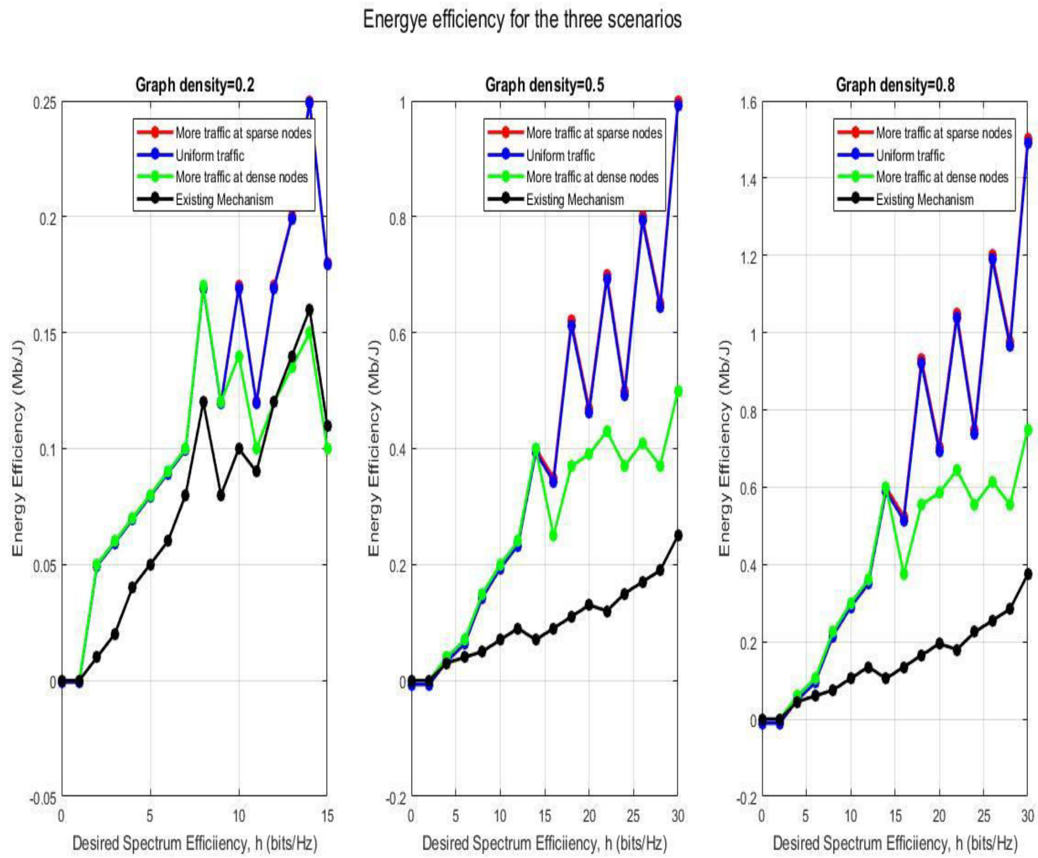
A D2D network can be modeled as a graph, Ge(V , e Ee), where Ve is the set of devices and Ee is the set of single hop links in the network. Let the edge graph of Ge(V , e Ee) by G(V, E). In the graph G(V, E), vertex2 i generates a fraction, gi of the total traffic in the system. The available system bandwidth, B, must be shared by all vertices of G. Links in Ge that do not interfere with each other can reuse the same bandwidth [48]. Thus, the corresponding vertices in G can reuse the bandwidth3 . To provide an achieved spectrum efficiency, it is essential to formulate an appropriate optimization problem, i.e., an appropriate objective function and appropriate constraints. We first formulate the constraints. In order to define the reuse constraints quantitatively, we provide the following definition from graph theory.

B. Energy Efficiency

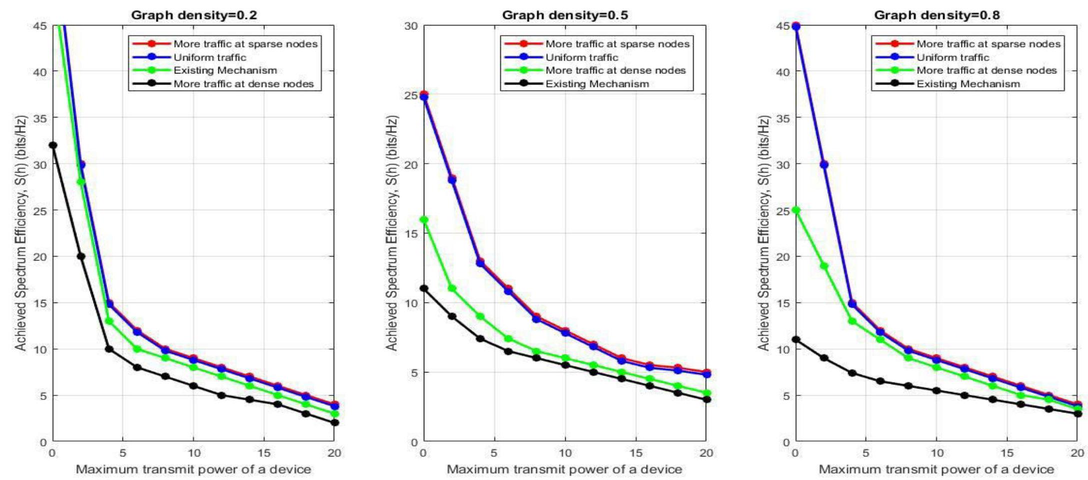
One means to reduce energy consumption (i.e., increase energy efficiency) is by all devices transmitting at power less than their maximum transmission power capacity. Another advantage that can be provided by lowering the power of transmission is that neighboring links of the network in Fig. 2 may be able to reuse the same bandwidth9 . However, reducing the power of transmission may cause degradation in the quality of the signal because of interference suffered from other concurrent transmissions using the same bandwidth.

3. SIMULATION RESULTS

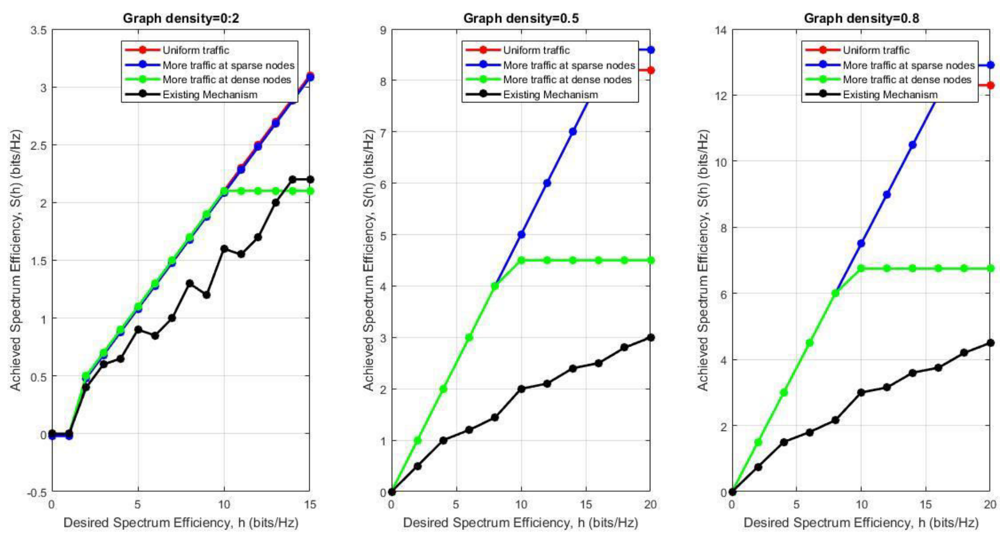



Energye efficiency for the three scenarios
Graph density=0.2
Graph density=0.5
Graph density=0.8
More traffic at sparse nodes
Uniform traffic
More traffic at dense nodes
Existing Mechanism
Energy Efficiency (Mb/J)
Desired Spectrum Efficiiency, h (bits/Hz)

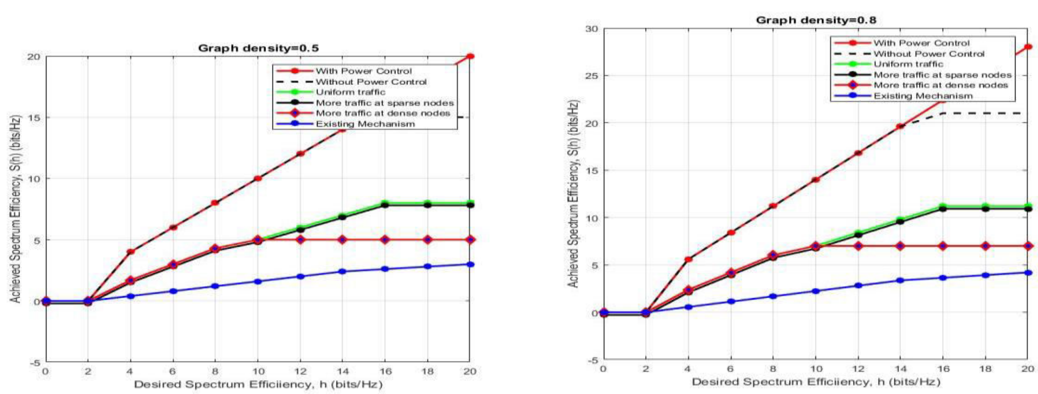
Spectrum efficiency for the three scenarios for varying values of transmit power



The achieved spectrum efficiency for the three scenarios.



The achieved spectrum efficiency after including the energy efficiency



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4.CONCLUSION

We presented a joint spectrum and energy efficiency mechanism that took the device traffic patterns and individual demands into account. The proposed approach is shown to provide an improvement between 25% to up to 4 orders of magnitude in spectrum efficiency and between 25% to up to 5 orders of magnitude in energy efficiency compared to existing mechanisms, depending on the network topology and traffic injection patterns of the nodes. Enhancement of the proposed approach to improve the overall system security is under investigation.

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