Multihop D2D Communication to Minimize and Balance SAR in 5G

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***Abstract*—To cope with the exponential growth in wireless traffic to be induced by the advancement of 5G and IoT technologies, higher frequency bands will be in use to achieve high performance. But this will enhance the associated electromagnetic field (EMF) around us and may have harmful effects on all living creatures and the environment, unless necessary precautionary measures are followed to limit it. In this paper, we propose an elegant method of band selection with appropriate data rate for multi-hop packet routing, to minimize and also to balance the transmission power and hence the associated EMF effect on us in terms of the *Specific Absorption Rate (SAR)*. Theoretical analysis has been presented for linear networks that results an upper bound on the number of hops permitted for a given spectrum band. Simulation results on random networks show that the proposed technique achieves a 30 - 70% improvement in terms of SAR, compared to the conventional direct communication via base station.**

Keywords: Electromagnetic field (EMF) effects, 5G, Cellular Communication, Specific Absorption Rate (SAR), Device to Device (D2D) Communication, IoT (Internet of Things).

I. Introduction

With the rapid increase in the usage of wireless technologies, exposure to associated radiation and the electromagnetic field (EMF) is becoming a major concern for any living being and our ecosystem. During recent years, it has been observed that the volume of wireless traffic is getting doubled in every four years [1], with an affinity towards higher frequency, resulting huge energy generated from numerous sources and being transmitted through space. It is a well-studied fact that the effect of EMFs on living creatures depends on the transmission power and the frequency as well. Several studies have reported findings on development of various health problems such as stress, headache, tiredness, anxiety, decreased learning potential, impairment in cognitive functions and poor concentration, as a result of exposure to microwave radiation emitted from mobile phones [2]. EMF disrupts the chemical structures of tissue since a high degree of electromagnetic energy absorption can change the electrical balance in the body [3]. As a result of this exposure, the functions of organs are affected. Though most of the studies considered the effects on human beings, lot of research reports also have been published on the effects of radiation on insects, birds and also on plants and vegetation [4].

This exposure occurs in the far-field and can be reduced by increasing the distance between users body and the source of the radio frequency (RF) radiation. For Wi-Fi systems, access points (routers) should be at least one meter away from where we are working. But in case of mobile hand sets, the distance cannot be increased much. EMF exposure also can be reduced by limiting the transmission power of the wireless devices. In the 5G or future wireless technologies, the prospect of multi-hop D2D communication techniques may enable us to reduce the transmission energy of the sources that in turn may help us to limit the harmful effects of associated EMFs on our ecosystem.

In wireless networks, it is a well-established fact that instead of routing packets directly, nodes may conserve significant amount of energy by routing packets via multiple hops through some intermediate nodes. To improve the network performance, multi-hop D2D communication has recently attracted many researchers [5] to forward packets via users' devices serving as relay nodes which results improved energy efficiency and outage probability. But the question is why a node will relay others traffic consuming its own resources, especially its limited energy reserve? It is a great challenge to motivate the individual users to serve as relay nodes. Various incentive schemes and policies have proposed in the context of ad hoc networks [6], [7]. In [8], authors proposed a novel energy incentive based technique of preferential band selection using cognitive radio for ad hoc IoT networks, and multi-hop D2D networks as well, to motivate nodes to serve as relay nodes to support multi-hop communication preserving its energy resource, and to achieve significantly better QoS and coverage.

In this work, we have investigated the multi-hop routing strategy for future wireless technologies and have proposed a novel technique for multi-hop packet routing with appropriate band assignment to reduce the EMF pollution in terms of SAR (Specific Absorption Rate) by balancing it across the network.

Analysis has been done for SAR balance on a linear network with uniform traffic generated at each node that represents a worst case scenario of load imbalance, and may be extended easily for random networks. Simulation results on random network shows the proposed technique will be highly effective for future wireless technologies to reduce the harmful effects of associated EMFs on our ecosystem.

The rest of the paper is organized as follows: Section II presents the theoretical background of the quantitative measure of the exposure amount and its dependency on related parameters. Section III describes the proposed technique

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for packet routing with SAR balancing, and its analysis on linear networks. Simulation results on random networks are described in Section IV. Finally the paper is concluded in Section V.

II. Quantitative Measure of Radiation Effects

By convention, the harmful effects of EMFs on human bodies, are measured in terms of the parameter called SAR *(Specific Absorption Rate)*. During mobile phone use, the temperature rises in human body parts due to exposure from strong EMF source. SAR is a quantity defined as the rate of RF power absorbed per unit mass of the body. In cellular communication, it is obvious that the handset transmits at maximum transmission power when it is either in the area with very low field strength of received signals [9], such as at cell boundaries, or under the influence of multi-path fading, or due to the presence of obstacles. SAR value is dependent on the distance of separation of the body and the radiation source expressed as:

$$SAR = \frac{\sigma E^2}{\rho} \tag{1}$$

where, E in (V/m) is the electric field, SAR is in $(Watt/kg)$, $\sigma(S/m)$ is the tissue conductivity and mass density of the tissue is $\rho(kg/m^3)$.

It is obvious that with the advent of IoT (Internet of Things), and 5G, there will be an exponential growth in wireless traffic on terrestrial paths intercepting not only the human beings but all the living creatures on the ground along with trees, plants and vegetation, having a great impact on our biodiversity. Hence, it is high time to propose new techniques to sustain the growth of wireless traffic minimizing its harmful effects on our ecosystem keeping the SAR value as low as possible.

Since, the effects of EMFs on living beings depend on the transmission power and the frequency of operation as well, it is important to investigate the relation between the two. From information theoretic point of view, Shannon-Hartley theorem says that the error-free information transmission rate k in $bits/sec$ is upper bounded as given by:

$$k \leq B \log_2(1 + SNR)$$

where B is the channel bandwidth in Hz, and SNR is the signal to noise power ratio at the receiver. So, minimum SNR required to receive data at a rate of k bits/sec, is given by:

$$SNR_r = 2^{k/B} - 1, \tag{2}$$

If $P_{r_{min}}$ be the minimum power to be received at the receiver and N_0 be the constant noise level at the receiver, then we get,

$$SNR_r = \frac{P_{r_{min}}}{N_0}.$$

Hence,

$$P_{r_{min}} = N_0(2^{k/B} - 1) \tag{3}$$

From the *Free Space Path Loss* model [10], to receive a minimum power $P_{r_{min}}$ at the receiver at distance D from the transmitter, the minimum transmission power should be:

$$P_{t_{min}} = G(\frac{4\pi Df}{c})^2(N_0(2^{k/B} - 1)) \tag{4}$$

where, G is a system dependent constant, D is the distance between transmitter and receiver, f is the frequency of transmission and c is the speed of light in free space.

Now for a transmitter, transmitting with a power $P_{t_{min}}$, the power density at a distance d_r in free space will be,

$$P_{d_{min}} = \frac{P_{t_{min}}}{4\pi d_r^2} watts/m^2 \tag{5}$$

From Poynting's theorem, the cross product of electric field vector E and the magnetic field vector H at any point is a measure of the rate of flow of electromagnetic energy per unit area at that point, given by,

$$P_d = E \times H \ watts/m^2 \tag{6}$$

Hence, from the theory of electromagnetic radiation propagation, assuming the impedance of free space to be approximately $120\pi\Omega$, from equation (5) and (6), result:

$$\frac{E|_{dr}^2}{120\pi} = \frac{P_{t_{min}}}{4\pi d_r^2}$$

$$E|_{dr} = \frac{\sqrt{30 P_{t_{min}}}}{d_r} \tag{7}$$

From equation (4), the field strength at a distance d_r will be,

$$E|_{dr} = \frac{4\pi GDf\sqrt{30N_0(2^{k/B} - 1)}}{d_r c}$$

So, we get the minimum value of SAR at that point, from equation (1) as:

$$SAR_{min} = \frac{\sigma(4\pi GDf)^2 30N_0(2^{k/B} - 1)}{\rho(d_r c)^2} \tag{8}$$

Equation (8) clearly shows that for wireless transmission, how the minimum SAR value at a point X depends on several parameters, the frequency of operation (f), distance of X from the transmitter (d_r), bit rate (k), distance between transmitter and receiver (D) and the bandwidth (B) of communication.

III. SAR Balanced Routing and Analysis

From equation (8), it is obvious that with a given frequency band of operation, a wireless network with shorter communication range D will be less harmful in terms of SAR. So, if we use multi-hop network for our future wireless technologies like 5G, then EMF effects will be minimized. In conventional cellular communication, even with the facility of transmission power control, the nodes at the cell edges have to transmit with maximum power to route their packets via base station, though the nodes close to the base station may limit their transmission power depending on their distance from the base station. In this respect, routing via multi-hop paths offers a good option for energy efficient routing. By the *Nearest Neighbor Routing (NNR)* [11], a node forwards its packets via nearest neighbors in multi-hop paths minimizing the power required at individual nodes and also the total power over the end to end path.

In this paper, a technique for packet routing via multi-hop paths over appropriate band is proposed to minimize, and balance the SAR values throughout the network. For analysis, we focus on linear networks that simply represents the worst case of load imbalance in multi-hop packet routing, as has been described later. Balancing of SAR over such networks shows that it can be easily applied to any random network as well.

Here, we assumed a linear network with n nodes, sending data packets following the *Nearest Neighbor Routing, NNR*, such that a node always forwards its packets to the nearest neighbor towards the receiver. Packet generation rate is same for all nodes. All nodes are transmitting data with a fixed transmission energy that is sufficient to cover a distance D, such that the network remains connected throughout its lifetime. It is to be noted that $D \ll D_{max}$, the maximum distance that a mobile device has to cover to reach the base station directly, i.e., the cell radius. Hence it is obvious that by *NNR* , the nodes will be able to transmit with much less power conserving energy significantly.

Each node is assumed to generate a single packet per unit time and forwarding the data to the nearest neighbor to finally reach the base station. As shown in Fig 1, it is clear that in every round, node n has to transmit its own packet and additional $(n-1)$ packets from all its preceding nodes, $(n-1), (n-2), \ldots, 2, 1$ and so on, whereas node 1 transmits only its own packet with zero relay load per unit time, i.e., the loads of the nodes are highly imbalanced. Hence, in an attempt to balance the transmission power, and the packet transmission time at each node, appropriate frequency bands along with matching bandwidth are assigned to support required transmission rates for each node with various loads. To balance the transmission time at each node, if node 1 transmits with a rate k bits per sec, node i with a load of i packets per unit time should transmit at a rate $i.k$ bits per sec. As a consequence, *NNR* will attempt to decrease the SAR value for all nodes by reducing the transmission power, but higher data transfer rate will result higher SAR value. So, to balance the SAR values across the nodes, appropriate frequency bands are assigned to the nodes depending on their loads as shown in Fig. 1.

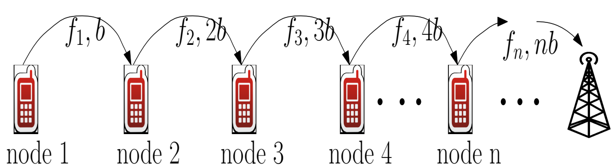

Fig. 1: A Linear Network with n nodes

Our objective is to achieve,

$$SAR_1 = SAR_2 = SAR_3 = \ldots = SAR_n$$

So, from equation (8), assuming all other parameters to be same for the network, we have,

$$(2^{k/B}-1)f_1^2 = (2^{2k/B}-1)f_2^2 = \ldots = (2^{nk/B}-1)f_n^2$$
$$or, (2^{k/B}-1)f_1^2 = (2^{nk/B}-1)f_n^2$$

For a given frequency spectrum of operation, $(f_{max} - f_{min})$ the maximum frequency band f_{max} can be assigned to the node with minimum load, i.e. node-1, and an upper bound on the value of n can be attained as:

$$n \leq \frac{B}{k} \log_2 \left(\left(\frac{f_{max}}{f_{min}} \right)^2 (2^{\frac{k}{B}} - 1) + 1 \right) \tag{9}$$

Here, n is the number of nodes in a linear network where SAR values are balanced for all nodes. Fig.2 shows the numerical results following (9), where transmission rate of transmitter is varied from 10 Kbps to 3000 Kbps for different frequency bands of operation. It shows that at higher frequency bands, the linear network may support larger number of nodes with balanced SAR values. But it decreases with increase in the minimum transmission rate k.

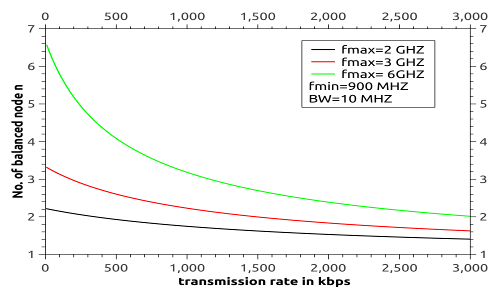

Fig. 2: No of balanced nodes(n)

So, from equation (9), number of balanced nodes can be calculated but to minimize the SAR value of each balanced node or to keep the SAR value of each balanced node within the safe level, transmission distance between the transmitter and the receiver plays a significant role. According to the FCC the safe limit of SAR [12] for human body is 1.6 W/kg. Fig. 3 shows the safe transmission distance for different transmission bands, assuming the transmission rate to be 1 Mbps. It is clear that at 2.4 GHz band the transmission range should be less than 80 m., and that essentially necessitates multi-hop communication, relaying packets through intermediate nodes to reach either the base station, or the destination.

IV. Simulation Study

Extensive simulation studies have been done to evaluate the performance of the proposed SAR balancing technique. In simulation we have considered one cell with radius 1000 m with 100 randomly distributed mobile nodes following random way-point mobility model with some boundary conditions. Here, nodes are sending data packets in multi-hop paths to the base station. We have measured the effective SAR value for human body at a distance of $2cm$ from the hand set. The

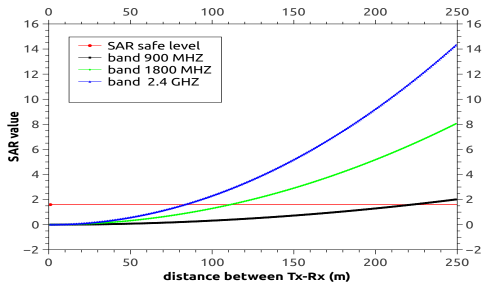

Fig. 3: Safe transmission range

traffic generation at each node follows Poisson arrival process with mean traffic arrival rate $\lambda = 10$ calls/sec. Similarly, the call holding time is assumed to follow exponential distribution with mean value $\mu = 2$ time units for all nodes. Network topology is not static, it is changing with time due to node mobility. We have implemented our proposed procedure for SAR minimization and balancing on Matlab. Total run time of the simulation is 2 hours.

Fig.s 4 and 5 show the comparison of SAR level with $k = 6Mbps$ for 2 hop, 3 hop and direct data transmission methods at different frequency bands. From these Fig.s it is evident that the proposed technique results nearly balanced SAR values across the network. In case of lower bands (Fig. 5), the reduction in SAR value with increase in number of hops is more prominent. As for example, in 900 MHz band SAR value is nearly 60% lower with 3 hops, compared to that with 2 hops, whereas for 2.4 GHz band the improvement is 30% only. For direct communication to the base station, the SAR values are much unbalanced, and communication by the proposed scheme via $2hops$ and $3hops$ result about 40%, and 70% improvement in SAR, over it, in LTE 8 band. The improvement is even higher in case of higher bands as is evident from Fig. 5.

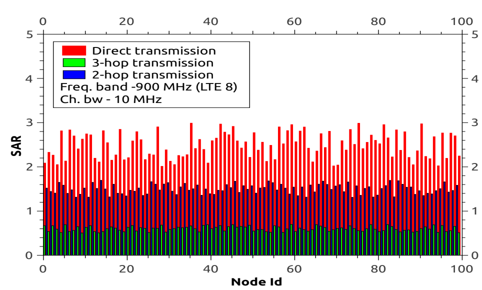

Fig. 4: SAR for LTE 8 band

V. Conclusion

In recent days, the volume of wireless traffic is growing at a tremendous rate. With numerous sources of wireless transmission around us, the associated electromagnetic fields affect our lives and our ecosystem in the long run. Necessary measures are to be taken immediately to protect our world against it. In this paper, we have proposed an elegant method of frequency and bandwidth assignment policy for multi-hop communication in mobile cellular networks that reduces the EMF and the associated SAR *(Specific Absorption Rate)* values to limit the harmful effects on living creatures. Analysis on linear networks establishes an upper bound on the length of a multi-hop path for a given spectrum. Extensive simulation results show that the proposed policy, nearly balances the SAR values across the network, and reduces the SAR values in the range of $30 - 70\%$ for different frequency bands. This shows that in the coming age of 5G with a wide spectrum available, the proposed technique will be very useful to select the appropriate path length, and frequency band according to the available spectrum to keep the SAR values within the safe limit, without compromising the QoS.

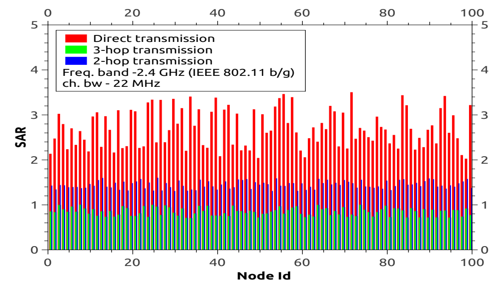

Fig. 5: SAR for IEEE 802.11g band

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