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A User Scheduling Scheme for Reducing Electromagnetic (EM) Emission in the Uplink of Mobile Communication Systems

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***Abstract*—The ubiquity and convergence of wireless communication services have contributed to an unprecedented popularity of mobile communications. Given that wireless communication systems operate on radiofrequency waves, the electromagnetic (EM) radiation exposure they generate is also unprecedented and, hence, this could have adverse health effects on both humans and animals according to the World Health Organization. In this paper, we propose a user scheduling/power allocation scheme to minimize the EM exposure of users subject to transmitting a target number of bits. Our user scheduling method is based on assigning priority levels to each user and the user with the lowest priority level is scheduled for transmission. Power allocation, on the other hand, is based on the water-filling approach over time by using the past channel gains of a user to compute its water level. Simulation results show that our proposed scheme performs much better than a spectral efficiency based scheme but has a higher EM emission in comparison with a non-practical ideal scheme.**

***Index Terms*—Power allocation, user scheduling, electromagnetic emissions, uplink, beamforming.**

I. INTRODUCTION

The increasing demand for data and multimedia services, and the ubiquitous nature of the current generation of mobile devices have resulted in continuous network upgrades to support an ever-increasing number of users. Interestingly, most research works have focused on optimizing the spectral efficiency (SE) and recently, the energy efficiency (EE) of mobile communication systems. However, because mobile communication systems operate on radiofrequency (RF) waves, the growth of mobile communication systems raises the level of electromagnetic (EM) emissions to the public. There are many concerns about possible adverse health effects due to exposure to EM radiation from mobile communication systems [1]. These worries are borne out of the popularity of mobile devices and the increased deployment of BSs closer to the general public in order to support the growing demand for bandwidth. Emissions from mobile phones present a serious health risk since the antennas are closer to the human body when in operation and the EM radiation is easily absorbed by the body. A 2011 report by the international agency for research on cancer (IARC) of the World Health Organization (WHO) concluded that EM radiation is possibly carcinogenic [2]. Hence, there is the need for a paradigm shift in research towards addressing the issue of EM emission in mobile communication systems [3].

In order to limit the amount of EM exposure to the user, the International Commission on Non-Ionizing Radiation Protection (ICNIRP) gave guidelines, in their reports [4] and [5], on the maximum admissible exposure of people to EM radiation up to 300 GHz for different practical situations and on the adverse effects of EM radiation exposure to health, respectively. As a result, the EM exposure of each mobile device is tested for regulatory compliance prior to device authorization or use [6].

There has been some research interests on reducing EM emissions in the uplink of mobile systems. The use of ferrite materials and metamaterials between the mobile phone and the human head proves to help in minimizing the EM emission to the user but affects the performance of the mobile antenna [7]–[9]. Another technique being investigated for reducing EM emission is beamforming; which refers to the use of an array of antennas to minimize interference and noise in order to improve the performance of the network. Although the beamforming technique has been traditionally used to improve the SE of mobile systems, it has been shown in [10], [11] that it can be used to minimize EM emissions in the uplink of mobile systems. However, these works mainly focus on reducing specific absorption rate (SAR) without considering the SE performance of the network.

User scheduling and power allocation have been used to improve the performance of mobile communication systems [12], [13]. These techniques have been thoroughly investigated in the past but mainly for maximizing the sum-rate of network. User scheduling and power allocation decide which user transmits at any given time and with what power. Given that EM emission is closely related the amount of energy (power over time) dissipated, user scheduling is an appropriate technique for reducing the EM exposure of each user within the network for a given transmission duration.

In this paper, we propose a novel user scheduling/power allocation scheme that minimizes the EM exposure of each user, subject to transmitting a target number of bits. Priority levels are assigned to each user based on its current and past transmit powers. The user with the lowest priority level in each transmission time interval (TTI) is scheduled for transmission. Whereas, the power allocation is based on the water filling approach over time, where the past channel gains of a user are used to compute its water level. In Section II, we first introduce the system model. Relying on this model, we then design, in section III, an EM emission-aware user scheduling/power allocation scheme for the uplink of a multi user system. In Section IV, we simulate the performances of our proposed scheme. Simulation results show that our proposed scheme achieves a lower EM emission compared to the classic SE approach, whereas, it has a slightly higher emission when compared to an ideal but non-practical EM reduction scheme. Conclusions are finally drawn in Section V.

II. SYSTEM MODEL

We consider, in this paper, the uplink of a single cell multi-user mobile system with K single antenna users transmitting to a base station (BS) equipped with a single antenna. The uplink transmission is assumed to happen over several frames, with each frame, F, containing $T = 10$ equally sized transmission time intervals (TTIs) of length l ms. We assume that a TTI is allocated to a single user for transmission, thus, occupying the whole bandwidth (similar to a time-division multiple access system). At each TTI, the BS computes the transmit power of each user and performs scheduling based on the priority level of each user in that TTI to minimize the EM emission of individual users subject to transmitting a target number of bits. Hence, the received signal-to-noise ratio (SNR) at the BS at TTI t is expressed as

$$\gamma_{k,t} = \frac{P_{k,t} g_{k,t}}{\sigma^2}, \tag{1}$$

where $P_{k,t}$ represents the transmit power of user k at TTI t, and σ^2 is the noise power. The parameter $g_{k,t}$ denotes the complex channel characteristics between user k and the BS at TTI t, which is assumed to be a quasi-stationary flat fading parameter. We assume that each user k has a perfect estimate of its channel gain and informs the BS by using the uplink feedback channel. Hence, $g_{k,t}$ is known at the BS. Therefore, the amount of bits that can be transmitted by user k at every TTI t is given as

$$b_{k,t} = W \log_2(1 + \gamma_{k,t}) l, \tag{2}$$

where W represents the channel bandwidth.

Given that the uplink EM exposure is defined as the product of the mobile device transmission energy and the reference SAR of the device [14], reducing the EM exposure comes down to reducing the transmission energy of the user. The total emitted energy towards user k for transmitting B bits is expressed as

$$\mathcal{E}_k = \sum_{t=1}^{N_k} P_{k,t} l \tag{3}$$

where N_k is the required number of TTIs by user k for transmitting B bits.

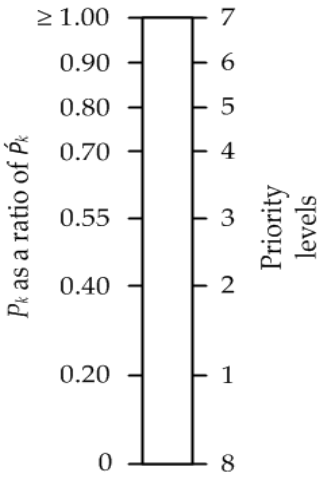

Fig. 1. Illustration of priority level assignment for user scheduling.

III. EM EXPOSURE-AWARE TRANSMISSION

As it can be seen in (3), the EM emission of each user is dependent on the transmission power utilized in each TTI and the number of TTIs used for transmission. Hence, it is important to select which user transmits in a given TTI in order to reduce the EM emission. In this section, we propose an EM exposure-aware transmission scheme that minimizes EM emission by performing optimal user scheduling and power allocation across the TTIs in a transmission frame, for all the users in the network.

A. User Scheduling

Our scheduling method is done by setting priority levels, $\mathcal{U}$, to each user based on the ratio between its current allocated power ($P_{k,t}$) and its maximum transmit power in the T TTIs of the preceding frame, denoted as $\tilde{P}_k = \max\{P_{k,t_0-1}, \ldots, P_{k,t_0-T}\}$ for each user k, where t_0 is the starting time of frame F. The priority levels are depicted in Fig. 1, where, if $0 < P_{k,t} \leq 0.2\tilde{P}_k$, a priority level of 1 is assigned to the user. Similarly, a priority level of 4 is assigned to user k if $0.55\tilde{P}_k < P_{k,t} \leq 0.7\tilde{P}_k$. The priority levels are designed to give priority to users with a chance of reducing their transmit power while taking into account their transmit power in the preceding frame. The user with the lowest priority level is chosen for transmission at each TTI.

User k ceases to transmit as soon as its target bits B is reached and, then, scheduling is done for the remaining users. Hence, the transmission time of the last TTI for user k can be expressed as

$$l_{N_k} = \left(\frac{B - \sum_{t=1}^{N_k - 1} b_{k,t}}{b_{N_k}} \right) l, \tag{4}$$

where b_{N_k} is the maximum number of bits that user k can transmit at TTI N.

Algorithm 1 EM Exposure Minimization Algorithm

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1: Inputs: $W, l, B, \sigma, P_k^{\max}, \mathcal{V}_k, \tilde{P}_k, g_{k,t}$, for $k = 1, 2 \ldots, K$
2: Initialize $t = 1$;
3: Compute $P_{k,t}^{\star}$ by using (7);
4: Compute and assign $\mathcal{U}$ for all users at TTI $t$;
5: Schedule user with lowest priority level for transmission;
6: Compute $b_{k,t}$ by using (2);
7: while $\sum_t b_{k,t} < B \; \forall k$, $t = t + 1$;
8: If $t = T$, then $F = F + 1$ and obtain $\mathcal{V}_k$ by using (8);
9: Repeat steps 3 to 8;
10: If $\sum_t b_{k,t} > B$, then obtain $l_{N_k}$ by using (4) and remove user $k$ from scheduling list;
11: Compute $\mathcal{E}_k$ via (9);
12: Output: $\mathcal{E}_k$.
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B. Power Allocation

Our objective is to find the optimal transmit power for each user at each TTI to minimize the EM emission, subject to transmitting a target number of bits B. The optimization problem is mathematically expressed as

$$\begin{aligned} \min_{P} \;\; & \mathcal{E}_k = \sum_{t=1}^{N_k} P_{k,t} l \\ \text{s.t.} \;\; & \sum_{t=1}^{N_k} W l \log_2(1 + \gamma_{k,t}) = B, \\ & \sum_{t=1}^{N_k} P_{k,t} l \leq \mathcal{E}_k^{\max} \end{aligned} \tag{5}$$

where $\mathcal{E}_k^{\max}$ denotes the total EM emission constraint of user k set by the system designer. In this paper, we assume $\mathcal{E}_k^{\max} = P_k^{\max} N l$.

Knowing that (5) is convex, we can define the Lagrangian associated with it as

$$\mathcal{L}(P, \lambda) = \sum_{t=1}^{N_k} P_{k,t} l + \lambda_k (B - \sum_{t=1}^{N_k} W l \log_2(1 + \gamma_{k,t})). \tag{6}$$

By inserting (1) in (6) and using the KKT conditions, i.e. solving $\nabla \mathcal{L}(P^{\star}, \lambda^{\star}) = 0$, we obtain after some simplifications the optimal power allocation over T TTIs is given as

$$P_{k,t}^{\star} = \left[\mathcal{V}_k - \frac{\sigma^2}{g_{k,t}} \right]_0^{P_k^{\max}}. \tag{7}$$

where $P_k^{\max}$ represents the maximum transmit power of user k at each TTI. Note that (7) resembles the classical water-filling power allocation strategy [15], where

$$\mathcal{V}_k = \lambda_k W / \ln(2) \tag{8}$$

represents the water level and λ_k denotes the Lagrange multiplier for user k. Newton-Ralphson method could be used to obtain the optimal values of λ_k. The k-th water level for the power allocation is computed based on user k's T channel gains of the preceding frame i.e., $\tilde{\mathbf{g}}_k = [g_{k,t_0-1}, \ldots, g_{k,t_0-T}]$.

TABLE I
SIMULATION PARAMETERS

Parameter	**Value**
Max. uplink power ($P_k^{\max}$)	125 mW
Mobile antenna gain	0 dB (omnidirectional)
Bandwidth (W)	2.5 MHz
Noise (n_0)	-165.2 dBm/Hz
Frequency (F)	2.1 GHz
Length of 1 TTI (l)	1 ms
Length of 1 frame	10 ms

Hence, the power allocation for each user at each TTI within the frame is based on the water level computed from the previous frame.

The total energy dissipated towards each user, i.e. user exposure, for transmitting B bits is given as

$$\mathcal{E}_k = \sum_{t=1}^{N_k - 1} P_{k,t}^{\star} l + P_{k,N_k}^{\star} l_{k,N_k}. \tag{9}$$

Algorithm 1 summarizes our simple approach for minimizing the EM emission towards each user subject to achieving a certain target number of bits, B.

IV. NUMERICAL RESULTS AND DISCUSSIONS

In this section, we compare our proposed EM-aware transmission scheme against an ideal scheme and an SE scheme in order to prove the reliability and performance of our scheme. The ideal transmission scheme assumes that all the channel gains of the users within a frame are known, based on a perfect prediction. Power allocation is then performed by using (7), where $\mathcal{V}_k$ is computed by using the predicted channel gains for each user. The transmit power for each TTI is sorted in ascending order such that transmission starts from the smallest non-zero power until the target for each user is met. The user is then scheduled to transmit at these TTIs. The SE scheme, on the other hand, allows users with the best channel gain to transmit at each TTI in order to push as many bits as possible. Hence, the user with the highest transmit power at each TTI is scheduled for transmission. Power allocation is based on the same principle as the proposed scheme. It is worth noting that the same number of transmission frames was used for transmission for all the 3 schemes compared in this paper. A Monte Carlo simulation of 10,000 iterations was done to achieve the results in this paper. The simulation parameters used are summarized in Table 1.

In Fig. 2, we depict the average EM emission per user of our proposed scheme against the ideal transmission scheme and the SE scheme normalized with respect to the ideal scheme for a 4 users network. It is evident that the ideal scheme has a lower emission compared to the proposed scheme and the SE scheme; however, it is not a practical scheme to implement

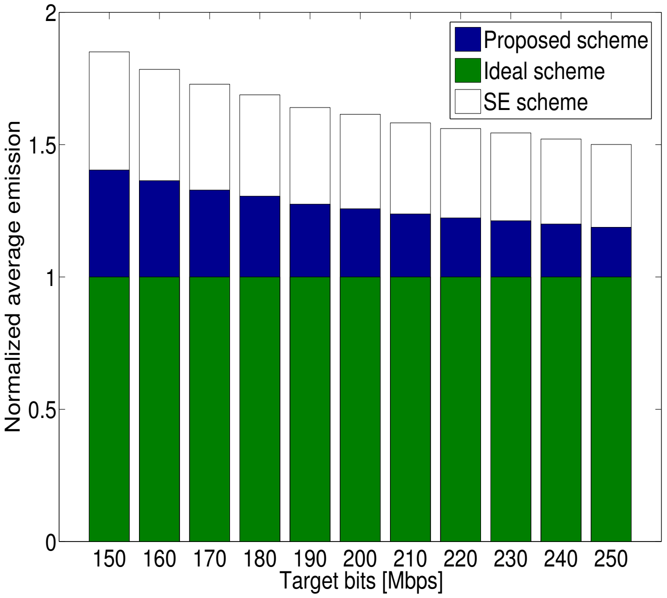

Fig. 2. Performance comparison of our proposed EM exposure-aware scheme against the ideal and SE schemes versus the target number of bits.

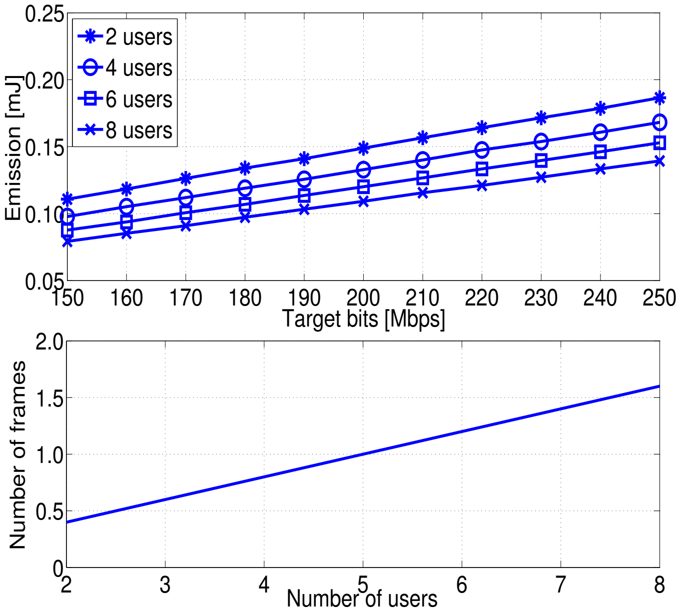

Fig. 3. Effect of increasing the number of users on the per user average EM emission of our proposed scheme.

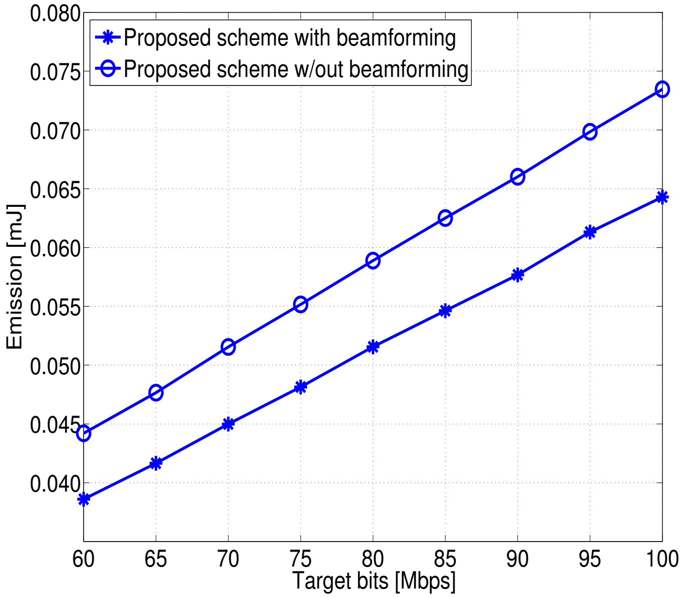

Fig. 4. Beamforming gain on EM emission for a 5 user network using our proposed scheme.

because the channel gains of all users have to be perfectly known in advance. Even though schemes like [16] and [17] can be used for channel prediction, the complexity and the accuracy of predicting up to a frame in the future affect practical implementation. It can be seen that although our scheme has a higher EM emission compared to the ideal scheme, the performance gap between the two schemes drops as the target number of bits increases. Our proposed scheme has about 40% more EM emission at a target of 150 Mbps, but this drops to about 20% at 250 Mbps. This is due to the fact that the users need more TTIs to transmit their data as the target bits increases and because the ideal scheme is assumed to have a prediction horizon of only one frame, all the TTIs in the current frame have to be scheduled for transmission before the next frame can be predicted. The SE scheme has the highest emission of the 3 schemes and it produces about 50% to 85% more EM emission compared to the ideal scheme. Although the SE scheme transmits with higher power to push in as many bits as possible at each TTI, the nature of the $\log$ function in (2) means that the amount of transmitted bits will not scale linearly with power. This results in a higher exposure to the users.

The top part of Fig. 3 shows the effect of increasing the number of users in the network on the EM emission. It can be observed that the average EM emission per user decreases as the number of users increases. This can be attributed to the fact that having more users in the network brings about a variety of channel gains and transmit powers since the channel gains of the users are independent and uncorrelated. For example, having one user in the network means the user would always be scheduled for transmission irrespective of the user's priority level. However, increasing the number of users in the network results in more options for scheduling and the priority levels are used to select which user is scheduled for transmission. Furthermore, it is evident from the bottom part of Fig. 3 that the number of transmission frames required to achieve the target bits of all the users increases linearly with the number of users in the network. This is because a user might require more than 1 TTI to achieve its target bits and the fact that the number of TTIs in a frame is fixed. Hence, it takes a longer period of time to achieve the target bits of all the users as the number of users increases. This, however, reduces the continuous EM exposure absorption of each user by scheduling other users between consecutive TTIs of each user.

Given that beamforming improves the spectral performance of wireless systems, we show in Fig. 4 that the use of beamforming with our proposed EM emission-aware transmission scheme can further reduce the EM emission in the system. The BS is assumed to have an array of 5 antennas and employ receive beamforming to improve the performance of the users in the network by focusing the main beam of the BS towards the desired user, thereby improving the received SNR. Each user estimates the channel between itself and the BS and feeds it back to the BS. The BS then computes the beamforming weights using the channel information and adjusts its antenna arrays to reduce noise and increase the SNR of the user. Power allocation and user scheduling are done using our proposed approach. The beamforming vectors are computed as proposed in [18] in the absence of interference. Fig. 4 shows the advantage of using beamforming for a 5 user network. It can be seen that beamforming reduces the average EM emission per user by as much as 15%.

V. CONCLUSION

We have proposed, in this paper, an EM emission-aware transmission scheme by using a simple user scheduling and power allocation algorithm towards reducing EM emission in the uplink. The proposed scheme is based on the use of priority levels for user scheduling while power allocation is based on water filling over time by using the past channel gains of each user to compute their water level. Simulation results show that our proposed scheme performs better than the classic SE transmission scheme but has a slightly higher EM emission compared to an ideal transmission scheme. However, the ideal scheme is difficult to implement in practice. In the future, we plan to incorporate beamforming in the proposed algorithm and also extend the proposed scheme to the OFDM scenario.

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