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Maximization Algorithm Design for Spectral and Energy Efficiencies in Full-Duplex Wireless Information and Power Transfer

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ABSTRACT:A communication system is consisting of a full-duplex (FD) multiple-antenna base station (BS), multiple single-antenna downlink users (DLUs) and single-antenna uplink users (ULUs), where the latter need to harvest energy for transmitting information to the BS. The communication is thus divided into two phases. In the first phase, the BS uses all available antennas for conveying information to DLUs and wireless energy to ULUs via information and energy beam forming, respectively. In the second phase ULUs send their independent information to the BS using their harvested energy while the BS transmits the information to the DLUs.
In the both phases the communication is operated at the same time and over the same frequency band. The aim is to maximize the sum rate and energy efficiency under ULU achievable information throughput constraints by jointly designing beam formers and time allocation. The utility function of interest is non-concave and involved constraints are non-convex, so these problems are computationally troublesome. To address them, path-following algorithms are proposed to arrive at least at local optima. The proposed algorithms iteratively improve the objectives with converge guaranteed. Simulation results demonstrate that they achieve fast convergence rate and out-perform conventional solutions.

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I. INTRODUCTION

Many of the developments of radio came during the two world wars. Spurred by the necessity of creating effective military communications, the U.S. government forced the communications companies and scientists to work together. At the same time many scientists in other countries were working to develop systems for their militaries. Marconi was the first to recognize the usefulness of short waves, these 1-100meter waves would use less power and travel less far and thus could hide information from a distant enemy as well as reduce interference with neighboring transmitters. Actually, short waves ended up being much more efficient than longer waves, used less power, and were not reflected off of the ionosphere (which prohibits daytime transmission) but were reflected off of a higher layer. More importantly, short waves could transmit information faster than 100 wpm. Several researchers also noted that ultra-short radio waves could be reflected from objects in their path, thus laying the basis for radar, a technology perfected during World War II.

While there were sporadic radio broadcasts of music and news to the public in both the US and Europe prior to World War I, these broadcasts, and indeed all amateur radio operation was shut down in the US during World War I for reasons of national security. Broadcasts were resumed in the fall of 1919 and the first radio station KDKA in Pittsburgh opened on Nov. 2, 1920 to begin daily broadcasts. The total number of radio operators in the US at that time was perhaps 30,000, so to ensure a listening audience the Westinghouse company manufactured cheap radio sets and when news of the broadcast spread the general public hastily bought parts to build their own sets. After the rapid success of broadcast radio, manufactures quickly improved their receivers, but yet, these sets cost on the order of $25-$400, a month’s wages, and needed frequent replacement of vacuum tubes. Compare this to the price and quality of a Walkman today! Introduction of the analog color and digital television sets saw the same problems. In 1954 the US saw its first color TV sets for sale for $1300, which was near the price of a car at that time.

Currently, you can purchase an HDTV set for \$5000-\$7000, still a significant amount of money.

The number of telecommunications innovations grew rapidly during the last half of the 20^{th} century. Currently there is widespread and growing use of cellular phones, cordless phones, digital satellite systems, and personal mobile radio networks. Wireless communications occur at many different frequencies, from underwater communication at extremely low frequencies on the order of tens or hundreds of Hertz, to infrared at 10^{14} Hertz. See Fig. 1 for a partial diagram of the radio frequency (RF) spectrum. In the United States the spectrum is allocated by the Federal Communications Commission (FCC).

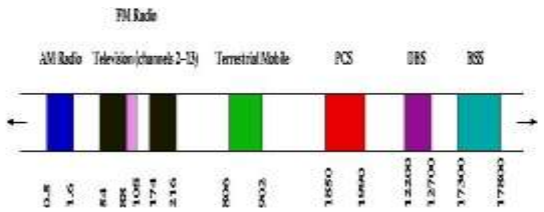


Fig. 1 A section of the RF spectrum showing some of the frequency assignments in MHz

A significant development in telecommunications in the United States was the 1996 Telecommunications Act. This act was written in part to promote competition (telecommunications had hitherto been controlled mainly by a group of monopolies), promote integration of advanced services to all Americans and development of the underlying infrastructure. Furthermore, it created measures, such as a rating code, to deal with viole
nce and obscenities, and laid out punishments for misuse, such as harassing phone calls, of the telecommunications systems.

II. SIGNAL PROPAGATION AND CHANNEL EFFECTS

Besides the lack of readily available bandwidth and the number of users who desire access to wireless systems, the largest obstacle to building systems is that of noise and fading. This was seen in the early transmission experiments, the Morse code dots and dashes were hidden in noise, making long-distance transmission a challenge. Noise in car radios is a familiar phenomenon, as you drive away from a transmitter, the station becomes noisier until it finally drops out and all you can hear is static. This effect derives from the decreasing power in a received signal as the transmitter-receiver separation increases. The power at the receiver is governed by the following equation where P_R and P_T are the received and transmitter power, respectively, A_R and A_T

$$P_R = P_T \frac{A_T A_R c^2}{\left(4\pi f d\right)^2}$$

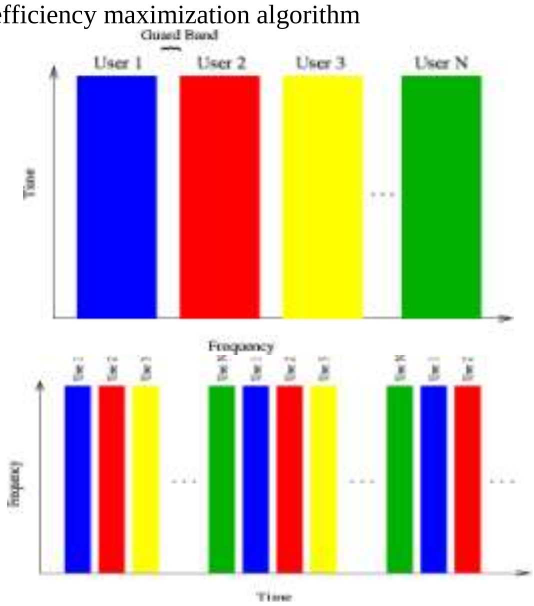
(1)

represent the amplification of the receiver and transmitter antennas, c is the speed of light $\left(3\times10^8\ m/s\right)$, f is the signal frequency, and d is the distance between the transmitter and receiver. We can see from this equation that the received power decreases with the square of the distance from the radio to the transmitting antenna.

2.1. Multiple Access

Until this point, we have discussed how to create a signal for one user, but the available bandwidth must be shared between many users. There are many methods of doing so; two of these methods, frequency division multiple access (FDMA) and time division multiple access (TDMA), are what is termed controlled multiple access, other methods such as code division multiple access (CDMA) and carrier-sense multiple access (CSMA) effectively permit users to access the channel whenever desired, under certain constraints.

3. Maximization Algorithm .Design high spectral efficiency and high throughput in wireless network system by using Sum rate maximization and energy efficiency maximization algorithm



(a) FDMA frequency division.
(b) TDMA time division.
Fig.2. Division of frequency or time in two multiple-access schemes.

Frequency division multiple accesses implies splitting the available spectrum between the users. This method broadcast radio and television stations deploy; each station is assigned a band (a certain range of frequencies in which they can transmit) and there is a short band in between the limits of each station called a guard band. The guard band is used to protect against flaws in the system such as carrier drift. A diagram of this is shown in Fig. In the U.S. analog cellular phone standard (AMPS) the channels are 30 kHz wide and there is a total of 832 channels in the system, each having a forward and a reverse link.

For the TDMA system each user has control of the total channel bandwidth for a short amount of time, then the channel is handed off to the next user. Each waiting user has a turn and then control is returned back to the first user. A diagram of a TDMA system is shown in. TDMA is used in the European cellular phone standard Global System for Mobile (GSM). Each channel supports 8 users; each user is allowed to transmit for 577 microseconds before it is the next user's turn.

Code division multiple access is a hybrid system, which allows all users to occupy the same bandwidth and time simultaneously. Essentially, everyone transmits at the same time; signals are differentiated at the receiver because they are orthogonal to each other.

The Orthogonality and knowledge of characteristics of the orthogonal signal make it possible to extract one user's signal from the entire transmission. The CDMA detection process can be envisioned as a noisy room. Without concentrating it seems as if what you hear is simply an unintelligible combination of sounds. However, if you can focus on a familiar voice, the words from this voice start to become distinguishable, and you can block out the background noise in the room.

CSMA is a method used in many wire line communications that can also be used for digital wireless communications. Each user's voice or data is broken into packets. The user then listens in on the channel in order to determine if anyone is transmitting. If the channel is unoccupied, then the user transmits. However, a collision occurs if two more users attempt to transmit at the same time. The receivers detect the collision and the users must retransmit their information at a later time. This system is only efficient if there is not a strict time constraint on the data, or if there are few users who wish to simultaneously transmit.

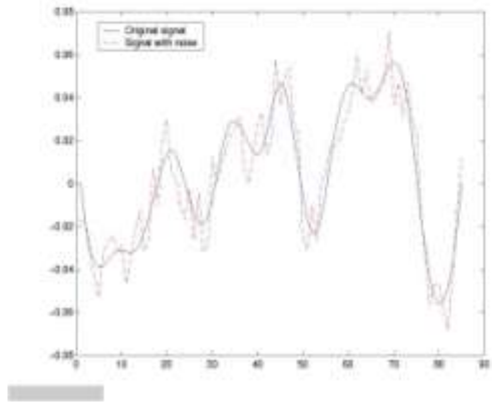


Fig. 3. A signal with noise.

In addition to noise, signals are often subject to fading. Signals can be reflected off of the ground, buildings, walls, trees or almost any object in their paths. One result of this is that, on average, the signal strength may decrease by a factor greater than the square of the distance. Furthermore, receivers at the same distance from the transmitter, but in different directions, may have greatly differing signal strengths. This phenomenon is accounted for by a path loss exponent, n, which is a number computed by many measurements in many areas and is the power to which the distance, d, in (1) is raised. It is further accounted for by a random number for each location at radius d from the transmitter. Thus, the power loss equation of (1) can be rewritten as $P_R = P_T \frac{A_T A_R c^2}{(4\pi f)^2 d^n} N$. (2)

In this equation, N is a noise factor, which is determined for different terrains and can capture some of the differences in signal strengths. The parameter n can take on values of 2 for free space loss (as in equation (1)), 4 for some urban cellular systems, and can range as high as 6 for intra building communication. Naturally, this parameter will vary depending on whether the signals can penetrate walls and how many buildings or other obstacles there are in the neighborhood.

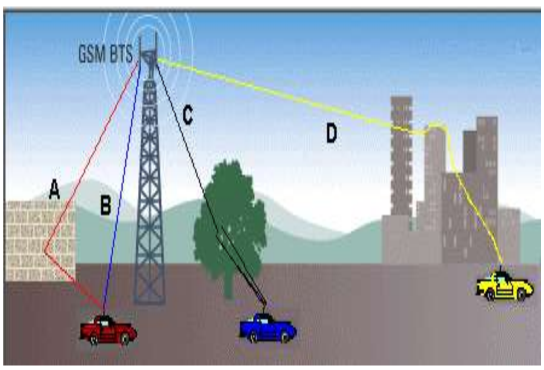


Fig. 4. Multipath fading.

Another problem called multipath add challenge to the signal transmission. Multipath is illustrated in Fig. 5,where four signals are received at the transmitter. Each of the four has travelled a different path and is received at a different strength. Thus, the total received signal is the sum of these four signals

$$r(t) = \sum_{i=1}^{4} a_i v(t - \tau_i) e^{j\varphi_i} \quad \text{........ (3)}$$

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$$r(t) = \sum_{i=1}^{4} a_i v(t - \tau_i) e^{j\varphi_i} \qquad (4)$$

Each signal on each path is delayed by time τ_i, and has amplitude and phase shifts a_i and φ_i respectively. One can imagine the difficulty in extracting an unknown signal embedded in many others. Finally, movement of the mobile will affect the received signal by producing a change in frequency. This, as with noise is a familiar phenomenon; think of the wail of an ambulance approaching and then leaving, the frequency increases and then decreases. If a sinusoid is transmitted, the received frequency is the sum of the transmitted frequency and the Doppler shift $f_R = f_C + f_D$,

where f_C is the transmitted sinusoidal wave. Assuming the receiver is co-linear with the mobile the Doppler shift is given by $f_D = \frac{v f_C}{c}$ where v is the velocity of the mobile. As the velocity increases (the mobile moves toward the transmitter) the apparent frequency increases, as it moves away the frequency decreases. Since mobile velocities are rarely constant, this frequency can change quite a bit, making reception a difficult prospect.

Therefore, it is obvious that there are many challenges in system design. Transmitters must be closely spaced closely or use large enough powers so that receivers can overcome the inherent system noise. If there is multipath, fading and Doppler shift, these must be compensated for either with careful signal design or intelligent receivers. One method of protecting against poor channels is channel coding. Bits are added to the bit stream in a controlled manner, so that if noise or fading degrades some bits, these lost bits can be recovered from others. Because the size of the bit stream is increased, the bandwidth must be increased proportionally in order to maintain the transmission rate. Thus, there is another tradeoff between protection against channel errors and bandwidth required. To design high spectral efficiency and high throughput in wireless network system by using Sum rate maximization and energy efficiency maximization algorithm .The aim is to maximize the sum rate and energy efficiency under ULU achievable information throughput constraints by jointly designing beam formers and time allocation. So, these problems are computationally troublesome. To address them, path-following algorithms are proposed to arrive at least at local optima.

The proposed algorithms iteratively improve the objectives with converge guaranteed. Simulation results demonstrate that they achieve fast convergence rate and outperform conventional solutions. i) Sum Rate Maximization Algorithm and ii) Energy Efficiency Algorithm.

III. SUM RATE MAXIMIZATION ALGORITHM

Finding an optimal solution to the SRM problem, is challenging due to the non-concavity of its objective function and non-convexity of its feasible set. In this section, we propose path-following computation procedure to obtain a local optimum.

SRM Problem Formulation: The SRM problem of jointly designing w1, w2, V, p, and α can be expressed as

Maximize RD (w1, w2, V, p, α) + RU (w2, p,α)

s:t: (1 -α) ln (1 + γℓ (w2; p))≥$\bar{r}_u$,∀ℓ=1…, L

P^2ℓ≤ $P^{eh}u_\ell$(w1, V, α), ∀ℓ=1………, L

Pℓ ≥ 0, ∀ℓ=1………, L

α(||w1||^2 + ||V||^2) + (1 – α) ||w2||^2 ≤$P_{BS,}$

0<α<1

Algorithm: Path-following algorithm for the SRM problem

Initialization: Set n: = 0 and $(\mathbf{w}_1^{(n)}, \mathbf{w}_2^{(n)}, \mathbf{V}^{(n)}, \mathbf{p}^{(n)}, \alpha^{(n)}, \tau^{(n)}, \beta^{(n)})$

1- repeat

2- Solve (48) to obtain the optimal solutions $(\mathbf{w}_1^{(n)}, \mathbf{w}_2^{(n)}, \mathbf{V}^{(n)}, \mathbf{p}^{(n)}, \alpha^{(n)}, \tau^{(n)}, \beta^{(n)})$

3- Update: $w_1^{(n+1)}$:= w^*_1 , $w_2^{(n+1)}$:= w^*_2 , $\alpha^{(n+1)}$:= α*, $V^{(n+1)}$:= V*, $P^{(n+1)}$:= P* , $T^{(n+1)}$:= T* and $B^{(n+1)}$:= B*.

4: Set n: = n + 1.

5: until Convergence.

- **Energy Efficiency Algorithm**

We now consider the EEM problem (19), which is also non convex and more computationally difficult than the SRM problem Again, we use the additional variables T and B.

EEM Problem Formulation: Another performance metricof interest is to maximize EE of the system.

Algorithm: Path-following algorithm for EEM (19)

Initialization: Set n: = 0 and solve(66) to generate an initial feasible point $\left(\mathbf{w}_1^{(n)}, \mathbf{w}_2^{(n)}, \mathbf{V}^{(n)}, \mathbf{p}^{(n)}, \tau^{(n)}, \beta^{(n)}, \lambda^{(n)}\right)$.

1- Repeat

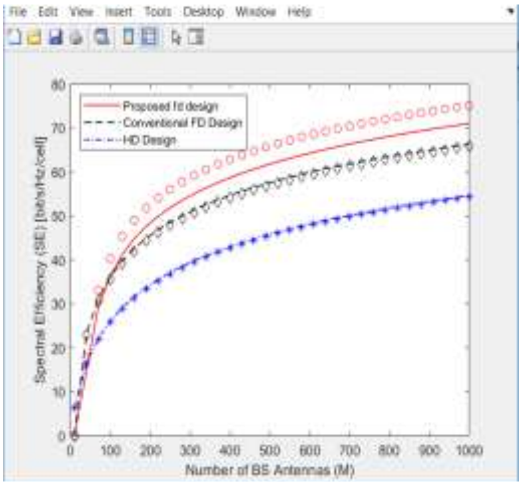
2- Solve To obtain the optimal solutions $\left(\mathbf{w}_1^{\star}, \mathbf{w}_2^{\star}, \mathbf{V}, \mathbf{p}^{\star}, \tau^{\star}, \beta^{\star}, \lambda^{\star}\right)$

3-Update: $w_1^{(n+1)} := w^*_1$, $w_2^{(n+1)} := w^*_2$, $\alpha^{(n+1)} := \alpha^*$, $V^{(n+1)} := V^*$, $P^{(n+1)} := P^*$, $T^{(n+1)} := T^*$,$B^{(n+1)} := B^*$ and $\lambda^{(n+1)} := \lambda^*$.

4: Set n: = n + 1.

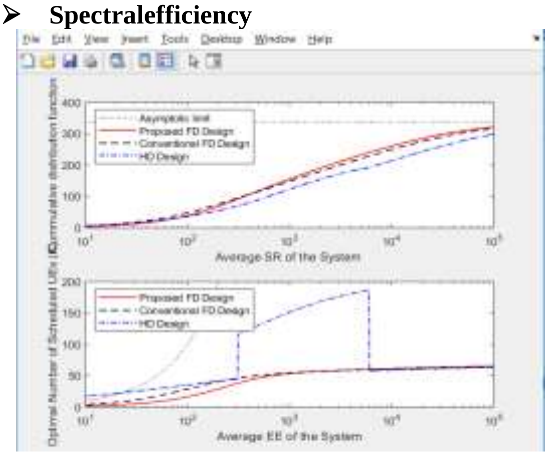
5: until Convergence.

- **Sum Rate Maximization**



- **Energy Efficiency**

- **Spectralefficiency**



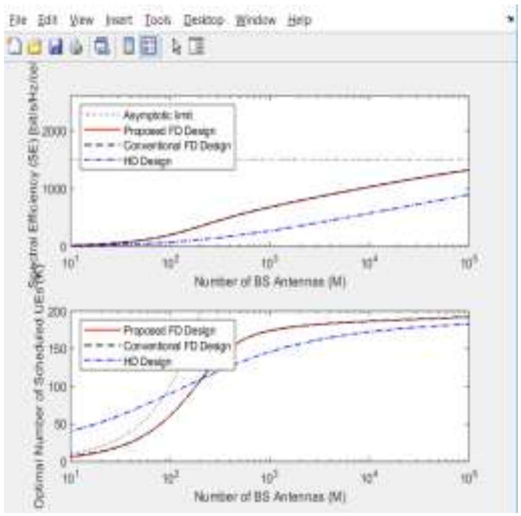


Fig:(2)

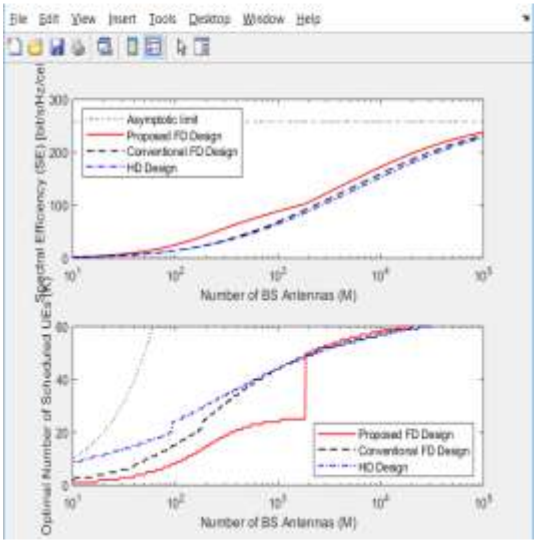


Fig:(3)

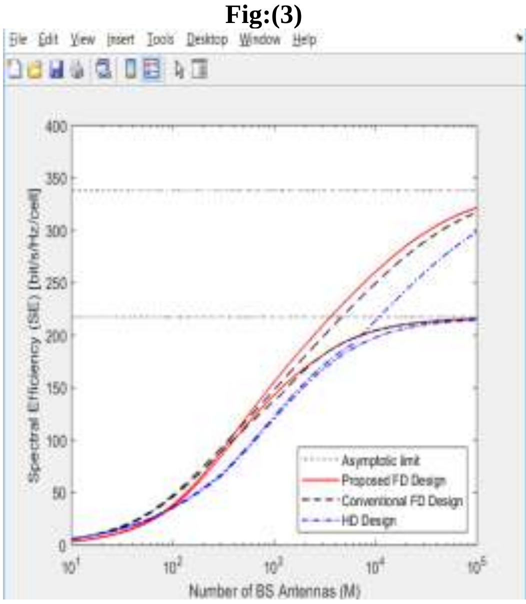


Fig:(4)

IV. CONCLUSION

We conclude that major thing in the wireless communication for increasing the spectral efficiency of the signals and also energy efficiency of the signals of both uplink and downlink .As far we know to increase the spectral efficiency we required huge equipment's but we consider here algorithms which works by applying to the uplink and downlink users ,based on the capacity of modules it increases the strength of the signal. Hence, we can say that for increasing of spectral as a sample module for MIMO networks .In the future we can develop a prototype and can be used as module and it can reduce the effort of designing the module as many number of ways.

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