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Low-Feedback Multiple-Access and Scheduling via Location and Geometry Information

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Abstract—**This paper exploits the use of location information of wireless terminals to improve the performance of a beamforming system and support multiple access. Based on a system providing real-time 3D coordinate information of all terminals in the environment, a novel feedback-free multi-user scheduler is proposed. It chooses a set of angularly separated wireless terminals for simultaneous transmission in order to reduce the impact of mutual interference on overall system performance. If additional feedback of signal-to-interference and noise ratio is available, a location-assisted multi-user scheduler is also suggested to further improve the overall system performance. Both multi-user schedulers are based on a rate-greedy approach. To improve the fairness in resource allocation without introducing additional feedback overhead, a modified proportional fair algorithm (PFA) based on location information can be applied to a beamforming OFDMA system. By scaling the window length of PFA, a range of trade-offs between fairness and rate can be achieved.**

Keywords-ViewNet, Location information, Beamforming, Multi-user Scheduling, Proportional Fair Algorithm

I. INTRODUCTION

Recently, there has been increasing interest in utilising location information to improve efficiency in resource allocation and enhance communication system performance [1]. The up-to-date location information can be provided by emerging augmented reality applications, such as the ViewNet project [2]. ViewNet aims to fuse mobile vision and location technologies to create context-enhanced networked services. The system efficiently captures accurate information about the current state of an environment and allows real-time 3D mapping of the environment. The core of the system is a visual simultaneous localisation and mapping (VSLAM) application which provides the 3D local coordinates of a moving camera while at the same time mapping the surrounding environment based on observations within the video stream [3]. The indoor and outdoor absolute location of the camera is obtained by an ultra-wideband (UWB) system or a global positioning system (GPS).

Knowing the current coordinates of the wireless terminals in the system allows the deployment of beamforming (BF) systems that can direct energy toward or away from specific terminals based on decisions as to which of them should have possibly concurrent access to the wireless sources. For the same transmit power, employing multiple antenna elements in an array improves the antenna gain. It allows multiple beams to be formed to support multiple spatially-separable wireless terminals simultaneously [4]. To perform beamforming, an ordinary wireless system generally requires additional bandwidth due to feedback overhead and processing time to obtain the relative positions / angle-of-departure (AoD) of the wireless terminals in the environment [5]. The advantage of the ViewNet system is that the coordinates of all the terminals are available straight away by running the application.

This paper will utilise the real-time geometry information available in applications like ViewNet to suggest a number of low-complexity and low-feedback multi-user scheduling strategies to improve transmission performance of a beamforming system. In order to select the group of wireless terminals achieving less mutual interference and improved overall rate, a low-complexity and feedback-free multi-user scheduling algorithm is proposed to exploit spatial multi-user diversity based on only the location information. The signal-to-interference and noise ratio (SINR) indicates the channel quality of a wireless terminal in the presence of interferences from other wireless terminals operating at the same time. If SINR information is also available at the transmitter, a location-assisted, low-complexity and sub-optimal greedy scheduler is also proposed to search for the group of wireless terminals achieving the near-optimal overall rate when transmitting simultaneously. The concern of fairness arises when terminals operate at different ranges and experience various channel qualities [6]. Compared to a conventional proportional fair algorithm (PFA) scheduling on the basis of rate, a location-based PFA is proposed along with the two multi-user schedulers to improve the fairness with minor degradation on the overall system performance. The location-based scheduling strategies proposed in this paper are applicable to any centralised systems, such as 3GPP LTE, WiFi, WiMAX, and potential future generation communication systems. In addition, the movement of vehicles can be well predicted in VANETs and therefore the proposed scheme can be also useful for V2V and V2I communications [7].

II. SYSTEM AND CHANNEL MODELLING DESCRIPTION

A. Beamforming for an OFDMA System

An OFDMA system is one of the most promising PHY and multiple access candidates for future communication systems. Considering a multi-user scenario, the total system bandwidth is divided into sub-channels, termed as physical resource blocks (PRBs), which can then be allocated to different terminals for multiple access purposes. The key parameters of the OFDMA based potential 4G communication system considered here are the same as those in [8] and are shown in TABLE I. There are 48 PRBs in the 100 MHz system, each consisting of 16 adjacent sub-carriers.

TABLE I. OFDM DOWNLINK SIMULATION PARAMETERS

Transmission Bandwidth	100 MHz
Operating Frequency	5 GHz
FFT Size	1024
Useful Sub-carriers	768
Guard Interval Length	176
Sub-carrier Spacing	97.656 KHz
Average number of user	25
Tx Power Level	17 dBm
Noise figure	-94dBm

B. Beamforming for Single-user Transmission

We assume that the base station is equipped with a uniform linear array (ULA) consisting of N_T antenna elements with a spacing of half wavelength λ, and there are K wireless terminals ($\kappa = \{1,2,\ldots,K\}$) each with a single receive antenna. Consider a plane wave incident on the array from an azimuth angle θ relative to the axis of the antenna array. Assume that all the array elements are noiseless isotropic antennas which have uniform gain in all directions. For downlink transmission of a beamforming OFDMA system, the signal transmitted from the base station antenna array to wireless terminal k is [8]:

$$\mathbf{U}_{k,s} = X_{k,s}\left[1, e^{-j2\pi\frac{d}{\lambda}\cos\theta}, \ldots, e^{-j2\pi(N_T-1)\frac{d}{\lambda}\cos\theta}\right]^T \quad (1)$$

where $[.]^T$ is the transpose function, and $X_{k,s}$ is the signal at sub-carrier s from wireless terminal k. The normalised steering vector is (only azimuth plane is considered):

$$\mathbf{W}_{k,s} = \left[W_0, \ldots, W_{N_T-1}\right]^H \quad (2)$$

$$= \frac{1}{\sqrt{N_T}}\left[1, e^{j2\pi\frac{d}{\lambda}\cos\theta_k}, \ldots, e^{j2\pi(N_T-1)\frac{d}{\lambda}\cos\theta_k}\right]^H$$

where $[.]^H$ is the Hermitian function, d is the antenna spacing at the BS, λ is the wavelength, and θ_k is the direction the beam points to. For applications like ViewNet, θ_k can be obtained from the location information of the wireless terminals which are known at the base station. The received signal at wireless terminal k becomes [4][9]:

$$Z_{k,s} = H_{k,s}\mathbf{W}_{k,s}^H\mathbf{U}_{k,s} \quad (3)$$

$$= H_{k,s}X_{k,s}\sum_{i=0}^{N_T-1}e^{-j2\pi\frac{d}{\lambda}(\cos\theta-\cos\theta_k)} = H_{k,s}X_{k,s}F_{k,s}(\theta)$$

where $H_{k,s}$ includes the fading effect and $F(\theta)_{k,s}$ represents the radiation pattern. The capacity of a single user beamforming scheme at sub-carrier s is given by:

$$C_{k,s} = \log_2\left(1 + SNR|H_{k,s}|^2|F_{k,s}|^2\right) \quad (4)$$

C. Beamforming for Multi-user Transmission

Beamforming can also spatially separate signals, allowing different wireless terminals to share the same spectral resources realising space-division multiple access (SDMA), provided that they are spatially-separable at the base station. The location information of different wireless terminals can be used for designing the beamforming vector. Assuming the base station simultaneously transmit to a sub-set of wireless terminals A_c, $\mathbf{X}_s$ represents the set of message signals at sub-carrier s. $\mathbf{W}_s$ is a set of normalised steering vectors. The base station transmits the superimposed signal of A wireless terminals from an array of N_T elements ($A \leq N_T$), and the SINR for each terminal is given by [9]:

$$SINR_{k,s} = \frac{P_k|H_{k,s}|^2|\mathbf{W}_{k,s}^H\mathbf{U}_{k,s}|^2}{\sum_{j\neq k}P_j|H_{k,s}|^2|\mathbf{W}_{j,s}^H\mathbf{U}_{k,s}|^2 + \sigma_{k,s}^2} \quad (5)$$

where P_k and $\sigma_{k,s}^2$ represent the signal and noise power of terminal k respectively.

D. Channel Model Parameters

The considered system is evaluated in the statistical channel model C of the ETSI BRAN channel models [10], which represents a typical large open space (indoor and outdoor) for non-line-of-sight (NLOS) conditions. It has a sampling period of 10ns and an rms delay spread of 150ns. All the analysis assumes 25 terminals in the environment.

1) Scenario 1
Wireless terminals are placed at equal distances from the base station. They are randomly distributed within a sector of 120-degree and experience the same SNR at 0dB.

2) Scenario 2
Wireless terminals experience different received SNRs, based on their relative location from the serving BS in a range of 100m in radius. Path loss is modelled based on the specifications in 802.11n [11]. The path loss model consists of the free space loss (slope of 2) up to a breakpoint distance d_{bk} and slope of 3.5 after the breakpoint distance.

$$PL_k(dB) = \begin{cases} 46.4 + 20\log_{10}d_k & , d_k <= d_{bk} \\ 46.4 + 20\log_{10}d_{bk} + 35\log_{10}\frac{d_k}{d_{bk}} & , d > d_{bk} \end{cases} \quad (6)$$

where d_k is the distance between the BS and wireless terminal k. The breakpoint distance d_{bk} here is 30m.

III. LOCATION BASED MULTIUSER SCHEDULER

A. Location-Based Scheduler for Multi-user Beamforming

Multiple beams can be formed and separated in different beamforming directions if location information of different wireless terminals is known. Instead of searching through all possible sub-sets of terminals, a low-complexity location-based multi-user beamforming (MU-BF) scheduler is proposed here and it aims to select a sub-set of wireless terminals that have a large inter-terminal angular separation in azimuth. The scheduler initially selects a targeted wireless terminal in a round-robin fashion, and then selects up to $N_T - 1$ terminals

which are angularly far away from each other for transmission.

1) Initialisation

- *Evenly divide the considered angular range Φ into N_T sub-sectors, each sub-sector covers an angular range of $[(i-1)\Phi/N_T, i\Phi/N_T)$*
- *Select a wireless terminal a_1 in a round-robin fashion and set $A_c(1) = \{a_1\}$*
- *Identify the sub-sector S_1 that a_1 is located at, and rank the other sub-sectors based on their angular separation to sub-sector S_1 in the descending order*

2) For $i = 2$ to N_T (start from the sub-sector furthest away from a_1)

Find the group of wireless terminals $B_c(i) \in \kappa$ within sub-sector S_i

If $B_c(i) \neq \emptyset$

Look through the wireless terminals in $B_c(i)$ and find $a_i = \arg\max_{k \in B_c(i)} \left(\min_{j \in A_c(i-1)} |\theta_k - \theta_j| \right)$

- *Set $A_c(i) = A_c(i-1) \cup \{a_i\}$*

End If
End For loop

Note that the performance of this algorithm depends on the exploitation of multi-user diversity and therefore it requires a sufficient number of terminals to be available in the environment if a large number of terminals are expected to be supported simultaneously.

B. Location-Assisted SINR-based Scheduler for Multi-user Beamforming

In addition to location information, if channel information (SINR) is also available at the BS, a performance improvement can be achieved over the location-only based BF proposed in section IIIA. Let A_c denote an arbitrary sub-set of terminals. For PRB c, if the index of the starting sub-carrier is m and finishing sub-carrier is n, according to a conventional rate-optimal greedy algorithm, the sub-set A_c^* achieving the highest overall rate is selected for transmission after searching all possible sub-sets of terminals:

$$A_c^* = \max_{A_c \in K} \sum_{i \in A_c} \sum_{s=m}^{n} \log_2(1 + SINR_{i,s}), \quad A_c \in \kappa \qquad (7)$$

However, the computation complexity of this conventional rate-greedy scheduler is high, especially when the number of wireless terminals is large. In order to reduce the complexity, an alternative sub-optimal rate greedy scheduling approach for beamforming is suggested here. The targeted terminal is initially chosen in a round-robin fashion. Then at each step, a terminal that maximises the overall rate R_{BF}^c is added to the chosen terminal sub-set. The process terminates if none-of the remaining terminals can further increase the overall rate, i.e. the introduced multi-user interference caused by adding a further terminal negatively affects the overall rate performance. Note $\cdot \backslash \cdot$ denotes set-subtraction.

1) Initialisation

- *Set $i = 1$*
- *Select a terminal a_1 in a round-robin fashion*
- *Set $A_c(1) = \{a_1\}$ and denote the achieved rate $R_{BF}^c = R^c(A_c(1))$*

2) For $i = 2$ to N_T

Find a terminal $a_i = \arg\max_{k \in \kappa \backslash A_c(i-1)} R^c(A_c(i-1) \cup \{k\})$

If $R^c(A_c(i-1) \cup \{a_i\}) > R_{BF}^c$

- *Set $A_c(i) = A_c(i-1) \cup \{a_i\}$*
- *Set $R_{BF}^c = R^c(A_c(i-1) \cup \{a_i\})$*

Else

No increase in rate is achieved and exits the loop
End If
End For loop

IV. LOCATION-BASED PROPORTIONAL FAIR ALGORITHM

The choice of the targeted terminal at the beginning of the multi-user scheduling process in Section III may not cause much impact on performance if all the terminals experience similar received SNR, i.e. channel scenario 1. However, in the case of Scenario 2, if a greedy approach is adopted, majority of the resources are unfairly allocated to the terminals which are closer to the transmitter and normally experience better channel conditions. A simple solution to improve fairness is to select the targeted terminal in a round-robin fashion as suggested in Section III. However, the overall system performance may degrade due to inefficient exploitation of multi-user diversity. In addition, the multi-user scheduling algorithms proposed in Section III can only be applied to an OFDMA system on a per-PRB basis, and therefore the scheduling decisions on all PRBs are independent.

The Proportional fair algorithm originally proposed by Tse [12] for single carrier schemes aims to guarantee greater throughput fairness amongst wireless terminals with unequal channel strength statistics. Based on the current rate calculated using the effective signal-to-noise ratio (ESNR) feedback of all wireless terminals, the PF algorithm in [12] assigns resources to a wireless terminal k with the highest ratio of the current data rate capability and the average throughput utilisation measured over a weighted window of length t_c. The extension of PF scheduling to multicarrier, OFDM transmission has been examined in [13].

In this paper, a modified PFA based on location information is proposed for a beamforming OFDMA system aiming to improve the fairness performance of the location-based multi-user schedulers. The targeted wireless terminal is selected based on the decision of this location-based PFA. It works on the assumption that wireless terminals closer to the BS generally have higher received SNR resulting in better data rate. The scheduler keeps track of the average distance $T_k(s)$ in a past window of length t_c and transmits to the terminal k^* with the lowest $d_k(t)/T_k(s)$ at PRB c at time t. The average

distance $T_k(s)$ is updated as follows:

$$T_k(s+1) = \begin{cases} (1-1/t_c)T_k(s) + d_k(t)/t_c, & k \neq k^* \\ (1-1/t_c)T_k(s) & k = k^* \end{cases} \quad (8)$$

where $s = t \times C + c$, C is the total number of PRBs per OFDM symbol. Due to the different distances from the BS, the channel condition of a wireless terminal closer to the BS is generally much stronger than the other wireless terminals on average, although channels fluctuate due to multipath fading. In the proposed PFA, wireless terminals do not compete for resources based on their absolute transmitter-receiver (Tx-Rx) distances $d_k(t)$ but after normalisation by their respective average Tx-Rx distances $T_k(s)$. The wireless terminal with a shorter Tx-Rx distance will be initially scheduled to transmit but will have a decreasing average distance. In contrast, the wireless terminals far away from the transmitter will gradually have a higher average Tx-Rx distance and therefore a reduced $d_k(t)/T_k(s)$ value. Thus, the algorithm schedules a wireless terminal when its Tx-Rx distance is low relative to its own average Tx-Rx distance over the window of length t_c. As the scheduling window length increases, the change in average distance $T_k(s)$ of each wireless terminal becomes less significant and the scheduling algorithm then gradually reduces to always picking the wireless terminal which is closest to the transmitter.

V. PERFORMANCE EVALUATION

The fairness performances of different schemes are evaluated using Jain's fairness index (JFI) [14]:

$$JFI(t) = \left(\sum_{k=1}^{K} g_k(t)\right)^2 \bigg/ K \sum_{k=1}^{K} g_k^2(t), \ g_k \geq 0 \forall k \quad (9)$$

where g_k is the rate achieved by wireless terminal k. The JFI varies between 0 and 1 and a larger JFI value indicates better system fairness.

A. Performance of Multi-user Scheduler in Scenario 1

The multi-user scheduling algorithms proposed in Section III are initially examined in Scenario 1. Employing multiple antenna elements in the array allows the formation of physically separated multiple beams to support simultaneous multi-user transmission and achieve better overall rate compared to a single-user beamforming (SU-BF) scheme as shown in Figure 1. The number of elements in the array indicates the maximum number of wireless terminals that can be supported simultaneously. A single-user single antenna system is also plotted as a reference. Adopting the location-based multi-user scheduler, as the number of supported wireless terminals increases, the data rate improvement due to antenna element gain and multi-user diversity gain becomes much more significant. The fairness performance also improves as more terminals are allowed for transmission simultaneously as shown in TABLE II. If further knowledge of channel condition (SINR) is available at the base station, the

multi-user diversity can be exploited more effectively for any array size to achieve an even better data rate as shown in TABLE II. This achievable rate based on the location-assisted SINR-based scheduler is considered as the reference rate in the paper. The results also show that the location-based scheduler is able to achieve a significant percentage of the reference rate (69.4%, 69.9%, 72.4% when 4, 6, 8 elements are in an array) and tends to perform better as the number of supported wireless terminals increases (more antenna elements in an array).
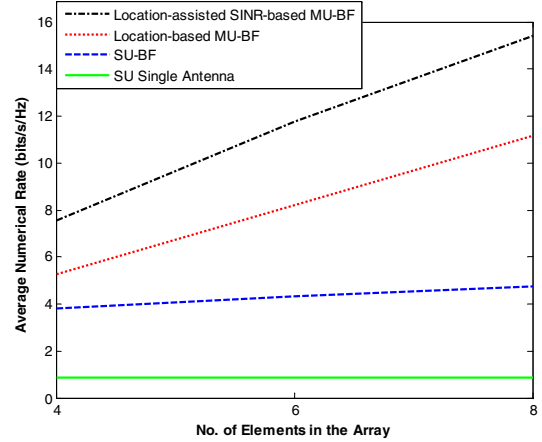

Figure 1. Numerical rate of single-user beamforming and multi-user beamforming based on location only or location-assisted SINR multi-user scheduler in the presence of 25 terminals (SNR=0dB)

TABLE II. AVERAGE JFI VALUES OF MU-BF BASED ON THE PROPOSED MULTI-USER SCHEDULING ALGORITHMS

Beamforming Scheme	No. of Elements in the Array		
	4	6	8
Location based MU-BF	0.325	0.389	0.439
Location-assisted SINR based MU-BF	0.651	0.656	0.672

B. Performance of PFA-based Multi-user Scheduler in Scenario 2

For wireless terminals experiencing independent channel conditions and received SNRs, fairness in resource allocation can be improved by applying the location-based PFA. An example of 4-element array is considered at the BS and it can support transmission of up to 4 wireless terminals simultaneously. The performance of selecting the targeted wireless terminal based on the greedy and round-robin approaches are also included for comparison. The average spectral efficiency η and JFI values of the location-PFA based multi-user schedulers are presented in TABLE III. and Figure 2. (a) and (b) which show the cumulative distribution functions of JFI values for location-based and location-assisted SINR based multi-user schedulers, measured over a number of channel realisations.

In the greedy approach, the targeted wireless terminal is always chosen to be the one that is closest to the transmitter resulting in the poorest fairness performance, although achieving the highest rate. The round-robin approach allows all the wireless terminals to have access to the resources, but the overall system rate is severely degraded. Compared to the

greedy and round-robin approaches, the resource allocation of different PRBs in the location-based proportional fair scheduler is no longer independent as each PRB is assigned based on the scheduling history of previous PRBs. The location-based PFA allows the window length to be scaled to meet a specific fairness and rate performance. With increased window length, the distance is averaged over a longer scale and therefore at majority of the times, the scheduler can afford to allocate resources to the wireless terminals that are closer to the transmitter and generally have better channel qualities. Therefore, the fairness performance degrades and the rate approaches the greedy algorithm.

TABLE III.   The Average Spectral Efficiency η and Fairness Performance of The Proposed Multi-user Scheduling Algorithms for an Array Size of 4

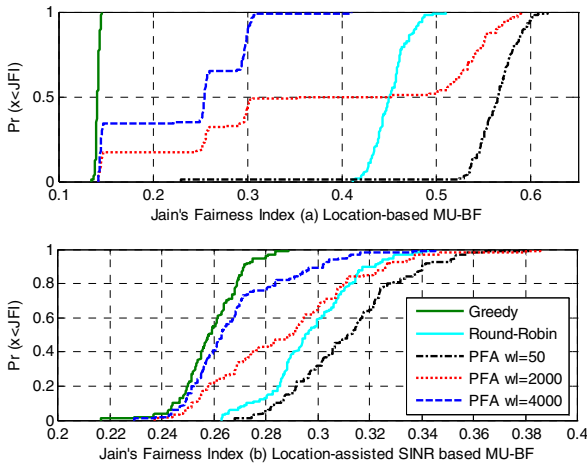| MU-BF Scheduler	Location only		Location-assisted SINR	
	η (bps/Hz)	JFI	η (bps/Hz)	JFI
PFA (wl=50)	20.78	0.563	31.23	0.312
PFA (wl=2000)	23.07	0.388	32.82	0.288
PFA (wl=4000)	24.30	0.234	34.18	0.268
Greedy	25.85	0.145	34.65	0.259
Round-Robin	20.16	0.452	32.25	0.297

Figure 2.   CDF of JFI for (a) Location-based MU-BF (b) Location-assisted SINR-based MU-BF employing greedy, round-robin and location-PFA with various window lengths (50, 2000 and 4000)

VI.   Conclusions

The availability of the up-to-date location information of the wireless terminals in ViewNet provides an opportunity for the scheduler of a system employing multiple antenna elements array to beam steer to the desired wireless terminal(s) with no or limited feedback requirement at the physical layer. A multi-user scheduling strategy based only on location information has been proposed for a SDMA beamforming system, and it aims to select a set of wireless terminals that cause reduced mutual interference and therefore achieve increased system throughput. Compared to this feedback-free scheme, a location-assisted multi-user scheduler based on the feedback of SINR is also proposed as a reference scheme to well exploit the spatial multi-user diversity and achieve better rate performance. By comparing the two schedulers, the results show the location-based scheduler is able to achieve a significant percentage of the reference system rate. The gap becomes even closer as the number of supported terminals increases. A proportional fair algorithm which also takes advantage of location information is proposed to improve the system fairness in addition to the rate improvement achieved by the location-based multi-user schedulers. By scaling the window length without introducing further feedback requirement, the PFA allows significant fairness improvements in exchange for minor rate loss.

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