Sensitivity Analysis of Location-aided Multi-user Scheduling Strategies to Imperfect Location Information

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Abstract—**When the location information is available, this paper presents the PHY strategies which can be applied to improve the performance of a beamforming system and support multiple access with low feedback requirement. Based on a system providing real-time 3D coordinate information of all terminals in the environment, feedback-free and low feedback multi-user schedulers are considered. The location-based schedulers are evaluated with both perfect and imperfect position information and the sensitivity of the system to location errors are measured in terms of both rate and fairness performance based on statistics of commercial GPS receivers.**

Keywords - Location information, Beamforming, Multi-user Scheduling, Imperfect Location Information

I. INTRODUCTION

In recent years, there has been growing interest in utilising location information to enhance the performance of physical layer of communication system [1]. The real time 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 to improve the effectiveness and cooperation between emergency services. 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). The system provides information about the physical environment around the wireless communication terminals, and allows storage of relevant quality information associated with time and location. This information can be exploited to develop new wireless physical layer capabilities.

With the availability of the current positioning information of the wireless terminals in beamforming (BF) system, optimum weights can be calculated and applied to the transmit signal to adjust the magnitude and phase of the signal to direct energy toward or away from specific terminals. Employing multiple antenna elements in an array improves the antenna gain and allows multiple beams to be formed to support multiple spatially-separable wireless terminals simultaneously [4]. Conventionally, beamforming 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]. Viewnet system has the advantage of providing the up-to-date coordinates of the wireless terminals by running the application.

This paper will exploit the location information available in applications like ViewNet and considers a number of low-feedback scheduling strategies for multiple access in a beamforming system. A multi-user scheduling algorithm that exploits spatial multi-user diversity based on only the location information is considered. 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 simultaneously. If SINR information is also available at the transmitter, a location-assisted sub-optimal greedy scheduler is also considered to search for the group of wireless terminals achieving the near-optimal overall rate when transmitting simultaneously. In practice, the position measurement accuracy is limited by various error sources. For the GPS receivers, the error sources mainly include satellite clock and ephemeris errors, atmospheric delays, thermal noise, interference and multipath [6]. The accuracy of UWB position estimation degrades with distance and even more so with non-line-of-sight (NLOS) scenarios [7]. Focusing on GPS based positioning system, this paper will consider both perfect and non-perfect estimation of position information and will investigate the sensitivity of the location-based multi-user schedulers to accuracy of position estimation.

The work presented in this paper is based on Long Term Evolution (LTE) downlink, which is the latest standard in the mobile network technology tree that previously realised the GSM/EDGE and UMTS/HSPA network technologies that currently dominate over 85% of the mobile phone global market [8]. It is introduced as Release 8 in the 3rd generation partnership project (3GPP) [9]. The new evolution aims to reduce packet delays, improve spectrum flexibility and further reduce the cost for operators and end users. The location-based scheduling strategies considered here are also applicable to other centralised systems, such as WiFi, WiMAX, and potential future generation communication systems. In addition, the movement of vehicles can be well predicted in a Vehicular Ad-Hoc Network (VANET) and therefore the proposed scheme can be also useful for (vehicle-to-vehicle) V2V and (vehicle-to-infrastructure) V2I communications [10].

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II. SYSTEM AND CHANNEL MODELLING DESCRIPTION

Considering a multi-user scenario, the performance analysis is performed on the downlink of a 3GPP LTE Orthogonal Frequency Division Multiple Access (OFDMA) system. The total system bandwidth is divided into sub-channels, denoted as physical resource blocks (PRBs), which are then allocated to different users for multiple access purposes. Note that a PRB is the smallest element of resource allocation assigned by the base station (BS) scheduler. The key parameters of the considered LTE OFDMA downlink system are given in TABLE I. The channel model used in the simulations is the Spatial Channel Model Extension [10] (SCME) Urban Macro scenario, specified in 3GPP [11]. SCME provides a reduced variability tapped delay-line model which is well suited for link level as well as system level simulation. Let λ denote the wavelength, low spatially correlated channel is assumed for all the users where 10λ spacing at the BS is employed. 2000 independently and identically distributed (i.i.d.) channel realisations are considered in each simulation. Consider a scenario that wireless terminals are placed at equal distances from the base station. Their positions are random and uniformly distributed within a sector of 120-degree and experience the same received SNR at 0dB.

TABLE I. SIMULATION PARAMETERS FOR LTE OFDMA DOWNLINK

Transmission Bandwidth	10 MHz
Time Slot/Sub-frame duration	0.5ms/1ms
Sub-carrier spacing	15kHz
Sampling frequency	15.36MHz (4x3.84MHz)
FFT size	1024
Number of occupied sub-carriers	601
Physical resource block (PRB) size	180 KHz (12 sub-carriers)
Total number of PRBs	50
Packet Size	54 Bytes
BS Tx Power	46dBm (40W)
Propagation Model	SCM Urban Macro
Path Loss Model	Cost-Hata [11]
Noise Power	-104dBm
User Equipment Noise Figure	6dB

III. SINGLE AND MULTI-USER BEAMFORMING

A. 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 ($\mathbf{K} = \{1,2,\ldots,K\}$) each with a single receive antenna. Assume that all the array elements are noiseless isotropic antennas which have uniform gain in all directions. Consider that a user of interest, k, is in the azimuthal direction θ_k from the axis of this antenna. In ViewNet, θ_k can be obtained from the location information of the wireless terminals which are known at the base station. The normalised beam steering vector is defined as [4][5]:

$$\mathbf{W}_k = \left[W_0,\ldots,W_{N_T-1}\right]^H = \frac{1}{\sqrt{N_T}}\left[1, e^{j2\pi\frac{d}{\lambda}\cos\theta_k},\ldots,e^{j2\pi(N_T-1)\frac{d}{\lambda}\cos\theta_k}\right]^H \quad (1)$$

where $[.]^H$ is the Hermitian function, d is the antenna spacing at the BS, and θ_k is the direction the beam points to. Let $\mathbf{H}_{k,s}$ be the $1\times N_T$ channel matrix for the sth subcarrier of terminal k, $X_{k,s}$ be its matching unit-power data symbol and $N_{k,s}$ be the Gaussian noise with zero mean and variance of $\sigma^2_{k,s}$. The received vector signal at wireless terminal k is [4][5]:

$$Z_{k,s} = \mathbf{H}_{k,s}\mathbf{W}_{k,s}X_{k,s} + N_{k,s} \quad (2)$$

The rate of a single user beamforming scheme without inter-user interference at sub-carrier s is given by:

$$R_{k,s} = \log_2\left(1 + SNR\left|\mathbf{H}_{k,s}\mathbf{W}_{k,s}\right|^2\right) \text{ bits/s/Hz} \quad (3)$$

B. 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 ($A \le N_T$), and assuming the perfect channel information is available at the terminal, the beamforming SINR for each terminal can be calculated as:

$$SINR_{k,s} = \frac{P_k\left|\mathbf{H}_{k,s}\mathbf{W}_{k,s}\right|^2}{\sum_{j\neq k}P_j\left|\mathbf{H}_{k,s}\mathbf{W}_{j,s}\right|^2 + \sigma^2_{k,s}} \quad (4)$$

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

IV. LOCATION BASED MULTIUSER SCHEDULER

A. Location-Assisted SINR-based Scheduler (SBS) for Multi-user Beamforming

With the knowledge of location and channel information (SINR), an optimal scheduler will require to search through all possible sub-sets of terminals and find the one achieving the highest possible overall rate. Here a low-complexity and sub-optimal rate greedy scheduling approach for beamforming is considered. For PRB c, let A_c denote an arbitrary sub-set of terminals. The flow chart of the scheduler is illustrated in Figure 1. At the beginning of the scheduling process, the targeted terminal is chosen in a round-robin fashion. Then at each step, the sum rate of each unscheduled terminal and the scheduled terminals is calculated and compared, and the terminal that maximises the overall rate R_c^{BF} is added to the chosen terminal subset. The scheduling process terminates if none of the remaining terminals can further increase the overall rate, i.e. the multi-user interference caused by adding a further terminal negatively affects the overall rate performance. Note '\' denotes set-subtraction.

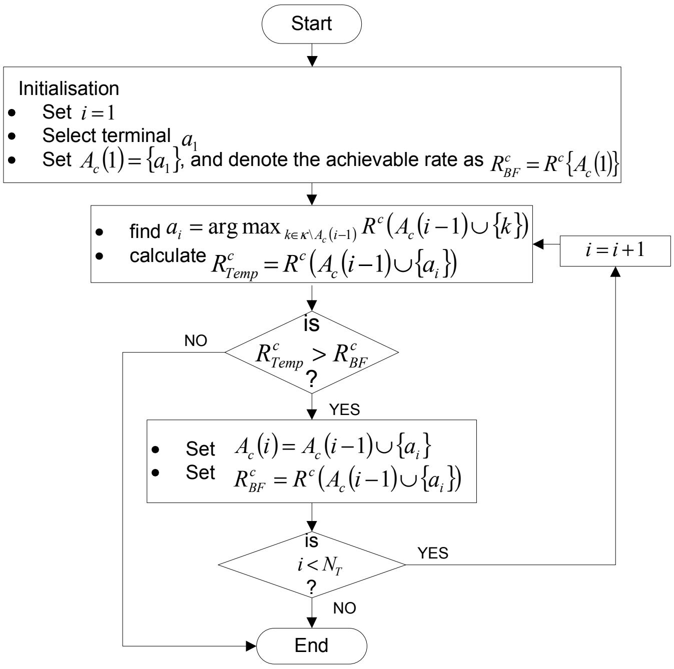

Figure 1. Flowchart for the Location-assisted SINR-based Scheduler

B. Location-Based Scheduler (LBS) for Multi-user Beamforming

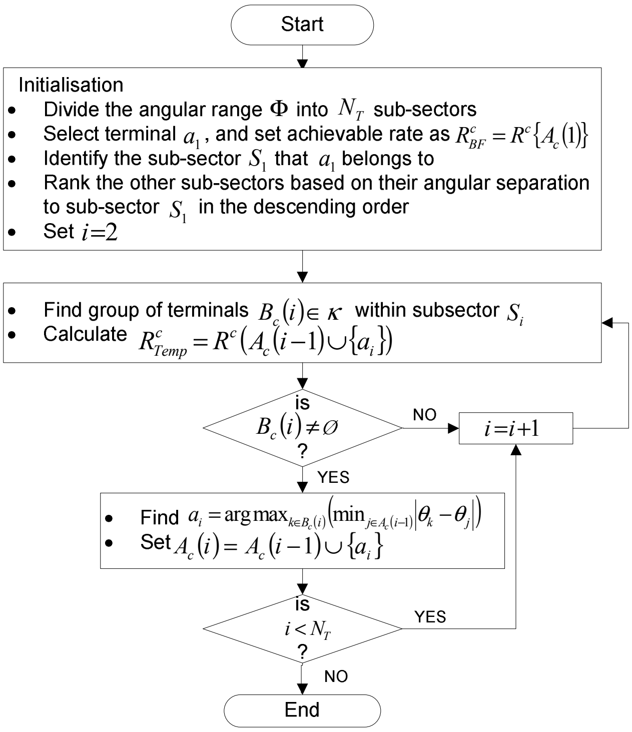

Figure 2. Flowchart for the Location-based Scheduler

If only location information is available, a low-complexity location-based multi-user beamforming (MU-BF) scheduler is considered here and it aims to select a sub-set of wireless terminals that have a large inter-terminal angular separation in azimuth, which is likely to suffer from less mutual interference. 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. Figure 2. shows the flow chart of the location-based scheduler. 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.

V. Sensitivity Analysis of Location-based Schedulers to Accuracy of Position Estimation

Assume the position error Δd_k of terminal k follows a 2D Gaussian distribution with mean $\mu_{\Delta d}$ and standard deviation $\sigma_{\Delta d}$. The azimuth angular error $\Delta\theta_k$ considered for analysis here is assumed to be the maximal angular error that can be caused by this position estimation error, which can be calculated as:

$$\Delta\theta_k = \arctan\left(\Delta d_k / d_k \right) \tag{5}$$

If the true azimuth direction of the desired terminal k is θ_k, the measured azimuth angle of the wanted terminal becomes:

$$\tilde{\theta}_k = \theta_k + \Delta\theta_k \tag{6}$$

As a result, the actual steering vector is expressed as:

$$\begin{aligned} \tilde{\mathbf{W}}_{k,s} &= \left[\tilde{W}_0, \ldots, W_{N_{T-1}}\right]^H \\ &= \frac{1}{\sqrt{N_T}}\left[1, e^{j2\pi\frac{d}{\lambda}\cos(\theta_k+\Delta\theta_k)}, \ldots, e^{j2\pi(N_T-1)\frac{d}{\lambda}\cos(\theta_k+\Delta\theta_k)}\right]^H \end{aligned} \tag{7}$$

The received vector signal at wireless terminal k then becomes:

$$\tilde{\mathbf{Z}}_{k,s} = \mathbf{H}_{k,s}\tilde{\mathbf{W}}_{k,s}^H\mathbf{U}_{k,s} = \sum_{i=0}^{N_T-1}(H_i)_{k,s} X_{k,s} e^{-j2\pi\frac{d}{\lambda}(\cos\theta - \cos(\theta_k+\Delta\theta_k))} \tag{8}$$

Due to the angular estimation error, the transmit signals no longer in-phase combine at the desired terminal and the received signal strength is degraded. In addition, the angular errors may also cause a rise in the sidelobe level [12]. Although a simple model for measurement error is considered here, the trends and behaviors of the location-based schedulers to position error apply to more sophisticated error models.

With different degrees of position errors, Figure 3. and Figure 4. show the resultant rate of LBS and SBS based beamforming in a 10- and 25-users environment respectively. As expected, the overall system rate decreases as the level of estimation error increases for both single-user and multi-user beamforming systems. In addition, for increasing number of beamforming antennas, the rate degradation of all systems becomes more significant. Among all the schemes, SBS-based multi-user beamforming system is least affected by the location estimation errors. For a system with 8 transmit antennas in a 25-user environment, compared to an error-free system, SBS-based system with an error level of STD=0.3 only suffers 12.15% rate loss. This is because SBS-based system performs scheduling based on the SINR feedback and the group of users that has the least mutual interference is scheduled after taking the estimation error into consideration. In the same situation, supporting a single-user, the rate loss due to estimation error in a multiple-input and single-output (MISO) system is around 12.98%. LBS based beamforming is the most sensitive scheme to the location errors and it suffers a rate loss up to 60%. This is because the position error causes a misjudgment in the actual relative angular separations among users and therefore the LBS scheduling algorithm can no longer work effectively and may choose a group of users with high mutual interference. Compared to a 25-user environment, the overall rate is lower in a 10-user environment because of less multi-user diversity. In addition, the mutual interference is less significant when the number of users in the environment is lower and they are more likely to be more spatially apart. As a result, the decrease in overall system rate due to location error in a 10-user environment is slightly less significant than a 25-user environment. For a system with 8 beamforming antennas in a 10-user environment, LBS and SBS-based system with an error level of STD=0.3 experiences 11.66% and 56.22% rate loss respectively. As shown in Figure 5. and Figure 6. for increasing level of position error, the rate-based Jain's fairness index also shows the fairness deteriorates as both the overall system and individual user's rate decrease. The decrease in fairness in a LBS-based system is more than a SBS-based system due to greater rate loss.

There are mainly three recognized GPS receiver grades: survey, mapping, and consumer (recreational) grade. The measurement accuracies of these three types of GPS receivers are within 1 centimeter, within 2 to 5 meters and within 15 to 20 meters of true position [13]. The statistics of the location estimation errors in this paper are based on the average measured data of five mapping-grade GPS [14] and six different consumer-grade GPS [13] in 3 scenarios including open sky, young forest and closed canopy conditions. To evaluate the sensitivity of the location-based beamforming to position estimation errors, the unprocessed mean azimuth position error Δd, which is the difference between the truth coordinate and the measured coordinate, together with its standard deviation (SD) indicating the variation of the errors from [13][14] are summarised in TABLE II. The percentages of the achievable rate of different schemes in the presence of position errors over the rate achieved by the same scheme in error-free case are presented in Figure 7. With similar average error level, compared to Consumer Scenario 2, the Mapping Scenario 3 experiences greater variation in errors, and therefore the achievable rate of LBS and SBS schemes are slightly degraded by less than 1%. The worst scenario is Consumer 3 with the highest mean and variation level of position errors and LBS is the most sensitive scheme to errors compared to other schemes and it suffers a rate loss of 3.6%.

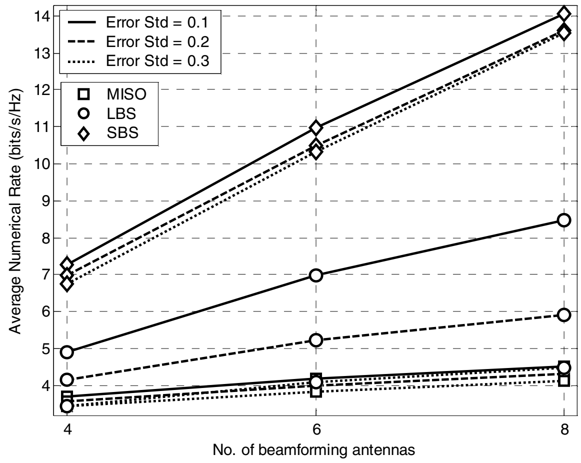

Figure 3. The Impact of position estimation error on the numerical rate of single- and multi-user beamforming based on LBS and SBS with 10 users. SNR=0dB

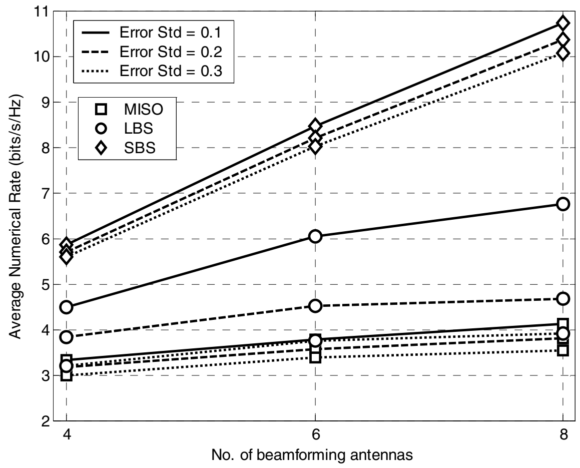

Figure 4. Impact of position estimation error on the numerical rate of single- and multi-user beamforming based on LBS and SBS with 25 users. SNR=0dB

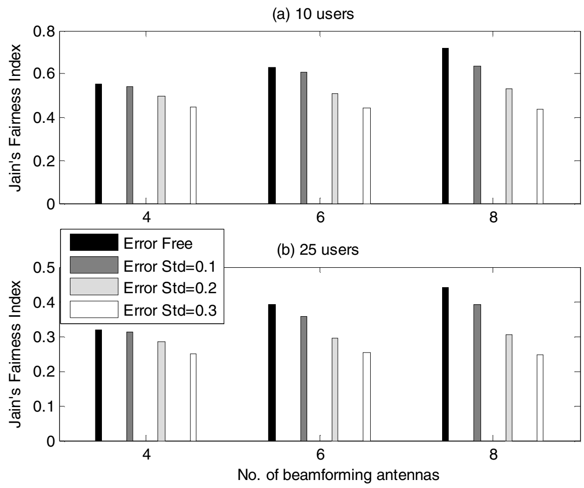

Figure 5. Impact of position estimation error on the average JFI of multi-user beamforming based on LBS with (1) 10 users and (2) 25 users. SNR=0dB.

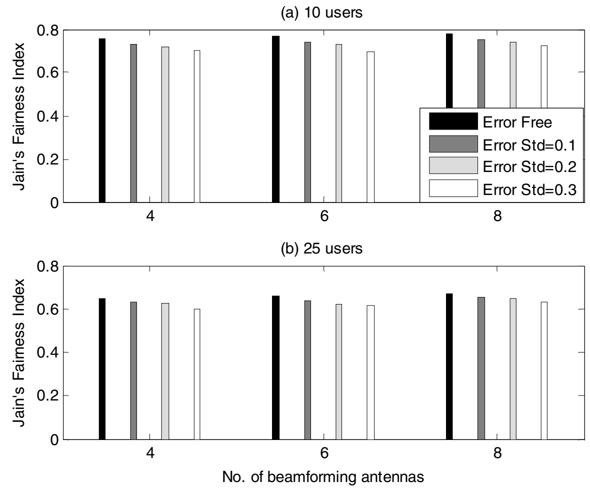

Figure 6. Impact of position estimation error on the average JFI of multi-user beamforming based on SBS with (1) 10 users and (2) 25 users. SNR=0dB.

TABLE II. AVERAGE POSITIONAL ERROR AND VARIATION OF SELECTED MAPPING AND CONSUMER-GRADE RECEIVERS [13][14]

	Mapping-grade GPS		Consumer-grade GPS	
	Ave.Errror	SD	Ave. Error	SD
Scenario 1	0.8	0.3	2.4	0.8
Scenario 2	1.3	0.7	3.5	1.1
Scenario 3	2.2	1.5	5.0	2.6

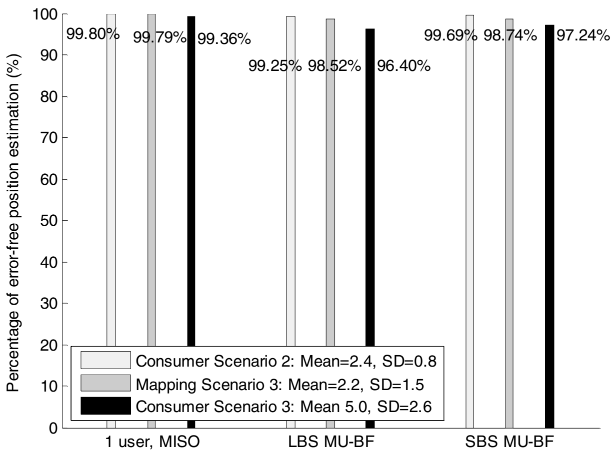

Figure 7. The rate performance of system experiencing location errors compared to error free transmission scenario in percentage. Support up to 8 out of 25 users. SNR=0dB

VI. CONCLUSIONS

Being able to provide up-to-date location information of the wireless terminals, systems such as ViewNet provide 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 scheduler based only on location information and a location-assisted multi-user scheduler based on the feedback of SINR is considered. The performances of the multi-user schedulers are evaluated with both perfect and imperfect location information. The position estimation accuracy levels of mapping-grade and consumer-grade GPS receivers are adopted for analysis. The scheduler based only on location information is shown to be most sensitive to errors, as the multi-user interference may increase if the location errors influence the scheduler to select a less favourite group of users for transmission. However, even for a commercial GPS receiver with the worst accuracy level, the location-based scheduler is able to achieve 96.4% of the ideal rate of an error free system.

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