Process-Oriented User Scheduling for Maritime Wireless Communications

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***Abstract*—Unlike terrestrial cellular networks, a maritime communication system has to cover a vast area with quite limited base stations (BSs) due to the limitation of geographically available BS sites. Therefore, the system usually adopts high-powered BSs, and reducing power consumption is especially a critical issue therein. In this paper, we reduce the power consumption by utilizing the process information, which has not been considered in the previous studies. As both the wireless channels and the service demand are time-varying, it is impossible to accurately predict the complete channel state information (CSI) and service requirements. To overcome these two difficulties, we exploit the positional information of each vessel based on its specific shipping lane and timetable to estimate the slowly varying large-scale channel fading instead. Besides, we particularly focus on the delay-tolerant information distribution service. On that basis, we formulate a power consumption optimization problem, which is proved to be NP-hard. We propose an efficient algorithm to solve it in an iterative way with a polynomial time complexity. Simulation results reveal that the proposed process-oriented scheme significantly reduces the power consumption, although it has not taken the small-scale channel fading into consideration.**

***Index Terms*—Process-oriented, maritime communications, user scheduling, large-scale channel fading**

I. Introduction

With the rapid development of marine industries such as marine tourism, offshore aquaculture and oceanic mineral exploration, there is growing demand of people involved in marine activities for mobile multimedia services. Thus, maritime communication systems that can provide reliable and high speed communications services like video surveillance and multimedia downloads are greatly needed [1][2]. Unlike terrestrial cellular networks, a maritime communication system has quite limited geographically available BS sites. In order to cover a vast area with limited BSs, the system usually adopts high-powered BSs, which increases the operational costs of mobile network operators and poses a global threat to the environment [3]. Therefore, reducing power consumption is especially a critical issue therein, and advanced wireless transmission and radio resource management techniques for maritime communications are pretty much required.

So far, several energy-efficient techniques have been developed for terrestrial cellular networks. In [4], a joint antenna-subcarrier-power allocation scheme was proposed for distributed antenna systems (DASs) with limited backhaul capacity to maximize the energy efficiency while providing min-rate guaranteed services. In [5], a matching algorithm of joint sub-channel assignment and power allocation was developed for non-orthogonal multiple access (NOMA) networks to maximize the total sum-rate with user fairness taken into consideration. In [6], a joint power allocation and user scheduling algorithm based on dynamic programming (DP) was proposed for multi-user MIMO systems to minimize the total energy consumption under hard delay constraints. In [7], a cross-layer cooperative user scheduling and power allocation scheme was developed for hybrid-delay services, and the fundamental tradeoff between delay and energy consumption was illustrated. More recently in [8], a user scheduling and pilot assignment scheme was proposed for massive MIMO systems to serve the maximum number of users with guaranteed quality of service (QOS). In summary, to improve the performance of an energy-efficient wireless network, two important aspects of QOS, i.e., the data rate [4][5][8] and the time delay [6][7], were utilized, and the channel state information (CSI) was assumed to be completely known beforehand [4]-[8].

However, as both the wireless channels and the service demand are time-varying, it is impossible to accurately predict the complete CSI and users' requirements during the service process. Therefore, all of the above user scheduling schemes are state-oriented, i.e, based on the current CSI and service requirements. As the service process information is ignored, the state-oriented schemes lose the potential gain in energy efficiency to a great extent, especially for maritime vessels with dynamic locations and service requirements.

In this paper, we focus on a new dimension to reduce the power consumption for maritime wireless communications by utilizing the service process information, which has not been considered in the previous studies. The major challenge for the process-oriented scheme lies in the prediction of the CSI and users' requirements during the service process. To overcome these two difficulties, we note that there are fewer scatterers on the sea than on the ground, making it easier to estimate and predict the slowly varying large-scale channel fading. Therefore, we exploit the positional information of each vessel based on its specific shipping lane and timetable to estimate the large-scale channel fading instead of the complete CSI. Besides, we particularly focus on the delay-tolerant information distribution service so that we can predict users' requirements during the service process. On that basis, we formulate a power consumption optimization problem for user scheduling, aiming to minimize the power consumption while providing users with min-rate max-delay guaranteed services. The problem is proved to be NP-hard. To overcome the difficulties of solving the NP-hard problem, we decompose the problem into two simpler subproblems, and propose an efficient algorithm to solve it in an iterative way with a polynomial time complexity. Simulation results reveal that the proposed process-oriented scheme significantly outperforms the state-oriented ones in terms of power consumption with the utilization of the service process information, although it has not taken the small-scale channel fading into consideration.

II. System Model

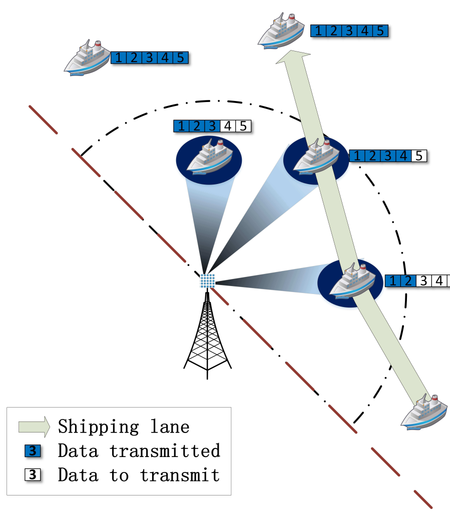

Fig. 1. Maritime communication system for information distribution service.

III. Process-Oriented User Scheduling Scheme

In this section, we focus on...

A. Energy Consumption Optimization Problem

$$E_{total} = \frac{\sum_{k=1}^{K} \int_{t=t_{k1}}^{t_{k2}} P_{k,t}}{\tau_d} + \tau_r \sum_{k=1}^{K} \int_{t=t_{k1}}^{t_{k2}} r_{k,t} + TLP_c \tag{1}$$

where $r_{k,t}$ is the channel capacity of user k at time t, τ_d is the drain efficiency of the radio frequency (RF) power amplifier, τ_r is the dynamic circuit power of the RF chain per unit bit rate, P_c is the static circuit power per BS antenna, and T is the total service duration of the system.

Thus, we formulate the energy consumption optimization problem as

$$\min_{\mathbf{Z}\in\{0,1\}^{K\times T}} E_{total} \tag{2a}$$

$$s.t.\ \ 0 \le P_{k,t} \le P_{\max} \tag{2b}$$

$$\int_{t=t_{k1}}^{t_{k2}} r_{k,t} z_{k,t} \ge C_k^{\min} \tag{2c}$$

$$z_{k,t} = \text{sign}(P_{k,t}) \tag{2d}$$

$$\sum_{k=1}^{K} z_{k,t} \le N \tag{2e}$$

where $\mathbf{Z} = \{z_{k,t}\}^{K\times T}$ and $P_{\max}$ represents the maximum transmit power. The constraint in (3e) is to guarantee that at most N users can be served simultaneously.

B. Process-Oriented User Scheduling Algorithm

The iterative algorithm proposed is specifically described in the table below.

Algorithm 1 Iterative Algorithm for Process-Oriented User Scheduling

while $\mathbf{Z}$ not feasible **do**
  Find $(k^*, m^*) = arg \min_{(k,m)\notin S_0} \left\{ r_{k,m_0} - r_{k,m}^{\max} \right\}$,
  where $\sum_{k=1}^{K} z_{k,m_0} > N$, $\sum_{k=1}^{K} z_{k,m} + 1 \le N$,
  and $m_{1k^*} \le m^* \le m_{2k^*}$.
  Set $P_{k^*,m^*} = P_{\max}$, $S_0 \leftarrow S_0 \backslash \{(k^*, m_0)\}$.
  while $\sum_{(k^*,m)\in S_0} r_{k^*,m}(\mathbf{Z}) < C_k^{\min}$ **do**
    Find $(k^*, m^*) = arg \max_{(k^*,m)\notin S_0} \left\{ r_{k^*,m}^{\max} \right\}$,
    where $\sum_{k=1}^{K} z_{k,m} + 1 \le N$ and $m_{1k^*} \le m^* \le m_{2k^*}$.
    Set $S_0 \leftarrow S_0 \cup \{(k^*, m^*)\}$.
  end while
  if $\sum_{(k^*,m)\in S_0} r_{k^*,m}(\mathbf{Z}) > C_{k^*}^{\min}$ **then**
    Set $P_{k^*,m^*} \leftarrow P_{k^*,m^*} - \frac{2^{\frac{\lambda}{B_s}} - 1}{\beta_{k^*,m^*} \sigma_s^2}$,
    where $\lambda = \sum_{(k^*,m)\in S_0} r_{k^*,m}(\mathbf{Z}) - C_{k^*}^{\min}$.
  end if
end while

IV. Simulation Results

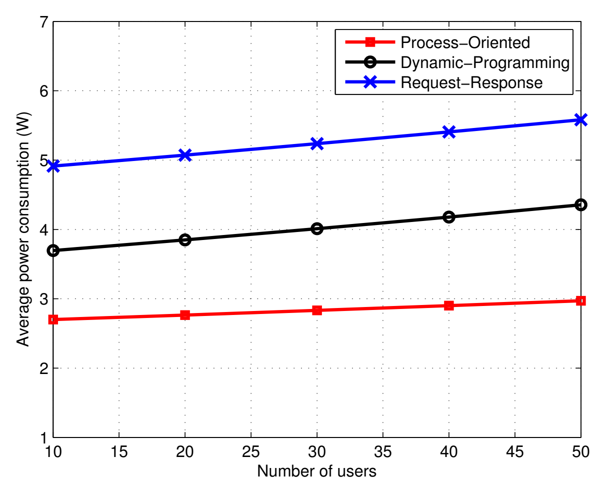

Fig. 2. Average downlink transmit power per user P_{avg} versus the number of users K for different user scheduling schemes.

V. Conclusion

Appendix A
Proof of Theorem 1

$$\begin{cases} A(k,(k-1)M+m) = r_{k,m}^{\max} & \text{(3a)} \\ A(t+K,(k-1)M+m) = -1 & \text{(3b)} \\ A(\text{others}) = 0 & \text{(3c)} \end{cases}$$

$$\mathbf{A} = \begin{bmatrix} 1 & 1 & 0 & 1 & 0 \\ 1 & 0 & -1 & 0 & -1 \end{bmatrix}, \text{and } \mathbf{b} = \begin{bmatrix} 1 \\ -1 \end{bmatrix} \tag{4}$$

Appendix B
Proof of Theorem 2

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