User Scheduling for Maritime Ship-to-Ship/Shore Communications

文章关注重点

- User scheduling

现有工作

- 陆地上US：
  - 需要CSI
- 海域US：
  - 有利用relay上传监控信息的工作

- US都需要CSI

贡献

- 利用大尺度信息：
  - 海域散射体较少，信道模型中大尺度更重要
  - 海域可以利用航线等，得到大尺度信息
- 对引入ship relay的US问题提出progressive approach 近似解

系统模型

- 频分，半双工，两跳
- 1个BS，J个用户
- N条载波，
  - 在每条载波上发射功率固定
- 用户QoS以data volume 衡量，
  - 延时容忍

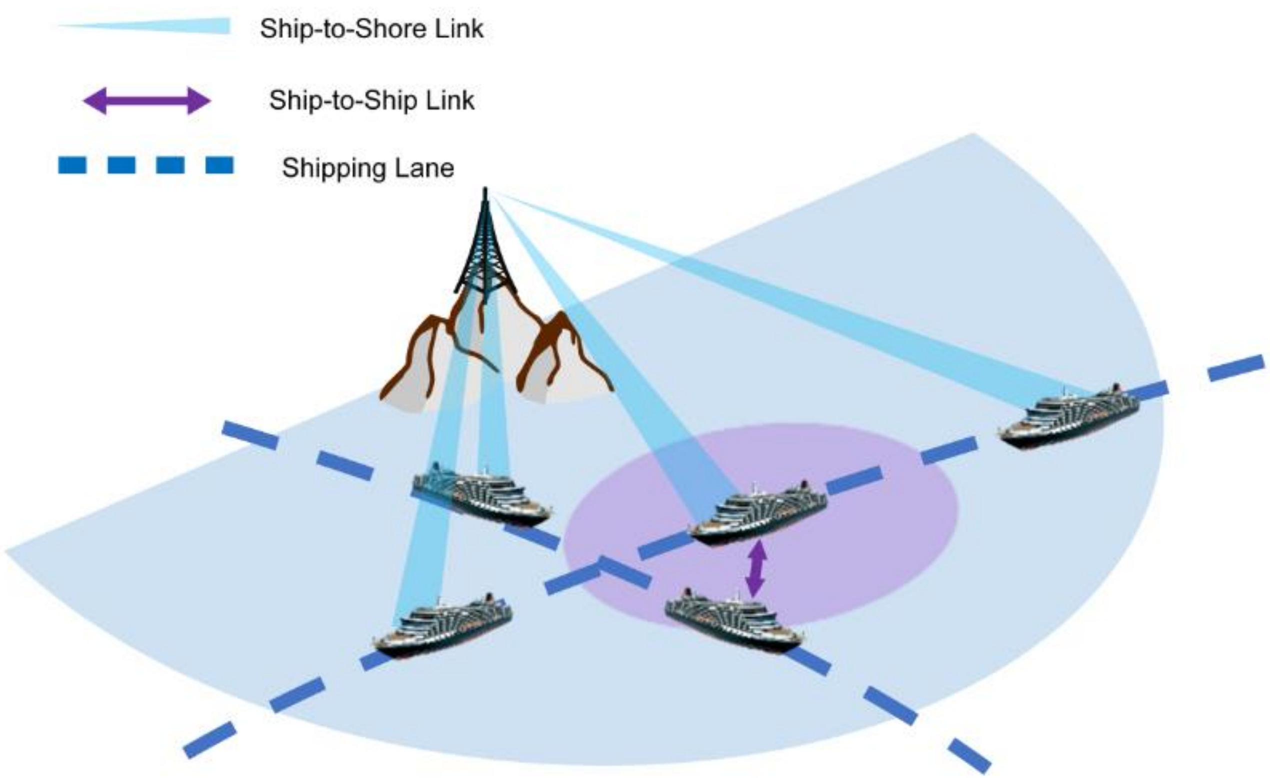


Fig. 1. Maritime ship-to-ship/shore communication system for data distribution service.

- 边"link":
  - 记录Tx (i)->Rx(j)@时隙(t)

paper by 'link' we mean the transmission from BS/relay to a user during a certain time period. Given that we only consider

大尺度

$$\beta_{i,j,\tau} = \left(\frac{\lambda}{4\pi d_{i,j,\tau}}\right)^2 \left[2\sin\left(\frac{2\pi h_t h_r}{\lambda d_{i,j,\tau}}\right)\right]^2, \tag{1}$$

- 大尺度衰落
- 传输速率

$$r_{i,j,t} = B_s \log_2\left(1 + \frac{P_i \beta_{i,j,t} |h_{i,j,t}|^2}{\sigma^2}\right), \tag{2a}$$

$$= B_s \log_2\left(1 + \gamma_{i,j,t} |h_{i,j,t}|^2\right), \tag{2b}$$

$$= (\log_2 e)\, e^{\frac{1}{\gamma_{i,j,t}}} \int_1^\infty \frac{1}{u} e^{-\frac{u}{\gamma_{i,j,t}}} du. \tag{2c}$$

- 时隙
  - 认为船只在时隙t内静止不动
  - 已去除最后的约等号。

优化问题

$$E_{total} = \sum_{j=1}^{J} E_j = \sum_{j=1}^{J} \left(\sum_{i=0}^{J} \sum_{t=1}^{T} P_i \delta_{i,j,t} \Delta\tau \right). \quad (3)$$

- 目标：总能耗
  - 只考虑了传输功率，其中tx向各个rx发射功率恒定，tx为BS或relay时功率不同
- $\delta_{i,j,t}$

By $\delta_{i,j,t} \in \{0,1\}$ we denote if a subcarrier is scheduled for the link $i \to j@t$. $\delta_{i,j,t} = 0$ means there is no transmission

$$V_{j,t} = \sum_{\tau=t_j^{\mathrm{B}}}^{t} \left(\sum_{i} r_{i,j,\tau} \delta_{i,j,\tau} - \sum_{j'} r_{j,j',\tau} \delta_{j,j',\tau} \right) \Delta\tau. \quad (4)$$

- 限制：数据量
  - 服务开始时间t_j^B，结束时间t_j^E

限制

- 半双工
- N子载波
- 中继最多把自己
  - 有的内容传完
- QoS限制
- 不需要记录在具体时隙给确定传输内容

$$\min_{\{\delta_{i,j,t}\}^{(J+1)\times J\times T}} \left\{ \sum_{i=0}^{J}\sum_{j=1}^{J}\sum_{t=1}^{T} P_i \delta_{i,j,t} \Delta\tau \right\}, \tag{5a}$$

$$s.t. \quad \sum_{i\neq j} \delta_{i,j,t} + \sum_{j'\neq j} \delta_{j,j',t} \leq 1, \tag{5b}$$

$$\sum_{i}\sum_{j} \delta_{i,j,t} \leq N, \tag{5c}$$

$$V_{j,t}\big|_{t=t_j^{\mathrm{B}}} = 0,\ V_{j,t}\big|_{t=t_j^{\mathrm{E}}} \geq V_j^{QoS},\ V_{j,t} \geq 0. \tag{5d}$$

Progressive approach

- 原问题 难
- 提出Progressive approach
  - 利用贪心思想，完成调度
- 三步approach
  - 1. 不考虑中继，不考虑子载波限制，最优解
  - 2. 考虑中继边的替代，对每个用户贪心
  - 3. 考虑子载波限制

Step-1 问题

- 无子载波约束，ship-to-shore

$$\min_{\{\delta_{0,j,t}\}^{J\times T}} \left\{ \sum_{j=1}^{J} \sum_{t=1}^{T} P_0 \delta_{0,j,t} \Delta\tau \right\}, \tag{6a}$$

$$s.t. \quad V_{j,t}|_{t=t_j^{\mathrm{B}}} = 0,\ V_{j,t}|_{t=t_j^{\mathrm{E}}} \geq V_j^{QoS},\ V_{j,t} \geq 0. \tag{6b}$$

Step-1

- 最优解
- 对每个用户，找速率最高的link，直至限制条件得到满足

Step-2 问题

$$\max_{\{\delta_{i,j,t}\}^{(J+1)\times J\times T}} \left\{ \sum_{j=1}^{J} \sum_{t=t_j^{\mathrm{B}}}^{t_j^{\mathrm{E}}} \left(\sum_{(0,j,t)\in\mathbf{S_2}} P_0\delta_{0,j,t} - \sum_{i=0}^{J} \sum_{(i,j,t)\in\mathbf{S_3}} P_i\delta_{i,j,t} \right) \Delta\tau \right\}. \tag{7}$$

- 最大化替换能量差
- 寻找最好的ship-to-ship/shore 替代边
- 先找到所有可行组合的集合R（替换边组合 速率 大于之前最优解）
- 对每个用户，贪心加入
  - 选择功耗速率比最低的一组替换边；
  - 若满足所有限制条件，则加入；
  - 直至集合R中不含接收者为该用户的边，或可以仅通过替换边满足QoS限制
- 对每个用户，贪心去除
  - 去除功耗速率比最高的一组原始边

$$\Delta E = \left[P_0 - \left(\frac{P_0}{r_{0,i',t_1}} + \frac{P_{i'}}{r_{i',j,t_2}} \right) r_{0,j,t_0} \right] \Delta\tau. \tag{8}$$

Step-2

- 算法

Algorithm 1 Suboptimal User Scheduling for Maritime Ship-to-Ship/Shore Communication System

Initialize $\mathbf{S_2} = \mathbf{S_1}$
Initialize $\mathbf{R} = \phi$ as group for all plausible ship-to-ship/shore links.
Find all ship-to-ship/shore links combination that have higher transmission speed than the original ship-to-shore only links. Store them in $\mathbf{R}$.
for all user j **do**
  while $V_{j,t}|_{t=T} < 2V^{QoS}$ **do**
    if there is no relay link with j as target in $\mathbf{R}$ **then**
      Break.
    end if
    Find ship-to-ship/shore links in $\mathbf{R}$ with lowest (best) composite power to rate ratio $\frac{P_0}{r_{0,i',t_1}} + \frac{P_{i'}}{r_{i',j,t_2}}$.
    if 'V_{i',t_2} is ENOUGH' AND 'i' & j & SYSTEM are FREE at t_2' AND 'i' & SYSTEM are FREE at t_1' **then**
      Add them from $\mathbf{R}$ to $\mathbf{S_2}$.
    end if
  end while
end for
while $V_{j,t}|_{t=T} \geq V^{QoS}$ **do**
  Find original ship-to-shore link in $\mathbf{S_2}$ with highest (worst) power to rate ratio $\frac{P_0}{r_{0,j,t_0}}$.
  Remove it from $\mathbf{S_2}$ for the substitution.
end while

算法中简写

- 确保替换过程满足
  - 全部限制

have "C_{i',t_2} is ENOUGH" in algorithm 3, which means

$$\begin{cases} C_{j',t_2-1} \geq r_0^{\min}\Delta\tau, if\, t_1 > t_2, & (10a) \\ C_{j',t_2-1} + r_{0,j',t_1}\Delta\tau \geq r_0^{\min}\Delta\tau, else. & (10b) \end{cases}$$

In algorithm 3, "i' & j & SYSTEM are FREE at t_2" means that

$$\begin{cases} \sum_{i^*\neq j}(\eta_{i^*,j,t_2} > 0) + \sum_{j^*\neq j}(\eta_{j,j^*,t_2} > 0) \leq 1, & (11a) \\ \sum_{i^*\neq i'}(\eta_{i^*,i',t_2} > 0) + \sum_{j^*\neq i'}(\eta_{i',j^*,t_2} > 0) \leq 1, & (11b) \\ \sum_{j^*}\sum_{i^*}(\eta_{i^*,j^*,t_2}) \leq N. & (11c) \end{cases}$$

And "i' & SYSTEM are FREE at t_1" means that

$$\begin{cases} \sum_{i^*\neq i'}(\eta_{i^*,i',t_1} > 0) + \sum_{j^*\neq i'}(\eta_{i',j^*,t_1} > 0) \leq 1, & (12a) \\ \sum_{j^*}\left(\sum_{i^*}(\eta_{i^*,j^*,t_1} > 0)\right) \leq N. & (12b) \end{cases}$$

Step-3

$$\min_{\{\delta_{0,j,t}\}^{J\times T}} \left\{ \sum_{j=1}^{J} \sum_{l=l_j^{\mathrm{B}}}^{l_j^{\mathrm{E}}} \left(\underset{(0,j,l')\in\mathbf{S}_3}{\delta_{0,j,l'}} - \underset{(0,j,l)\in\mathbf{S}_2}{\delta_{0,j,l}} \right) P_0 \Delta\tau \right\}. \tag{12}$$

- 只有step-1 中的最优解可能不满足子载波限制；
  - Step-2中新加入的替代边满足全部限制；
  - 会增加系统能耗
  - 最小化替换之差
- 寻找ship-to-shore边中不满足限制部分。
- 对每个不满足限制的时隙，贪心去除
  - 去除功耗速率比最高的一组原始边
- 对该去除一条边的用户，贪心加入
  - 选择功耗速率比最低的一组替换边；

Step-3

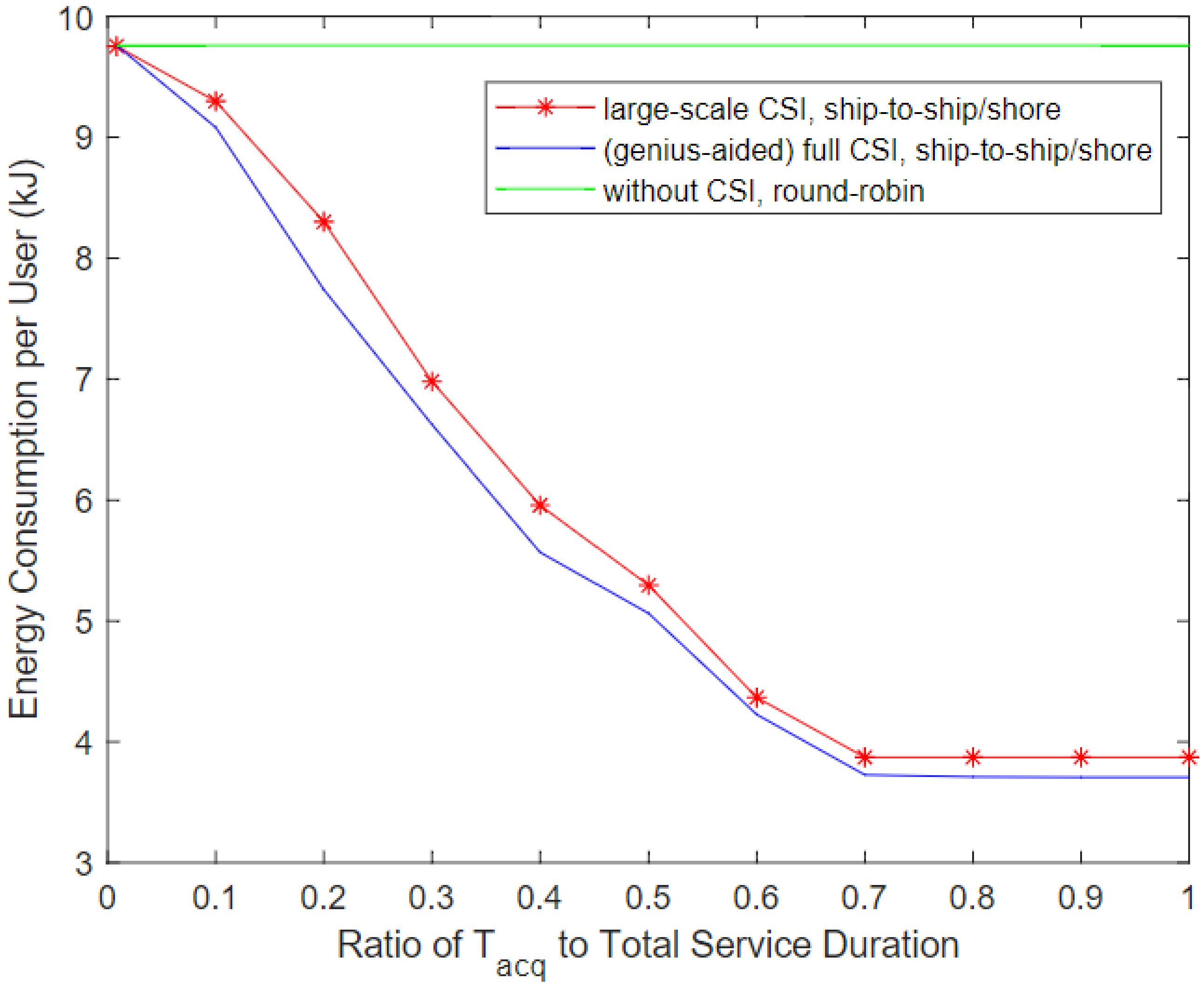
- 算法

Algorithm 2 Subcarrier Constraint Adjustments

```
Initialize S_3 = S_2
for all t do
    if Σ_j η_{0,j,t} ≤ N not met then
        Find original link in S_3 that have the highest (worst) power to rate ratio P_0 / r_{0,j,t_0}.
        Remove it from S_3.
        while V_{j,T} ≥ V_{j,QoS} not met do
            Find ship-to-shore only link or ship-to-ship/shore links with lowest (best) composite power to rate ratio.
            Add it/them to S_3.
        end while
    end if
end for
```

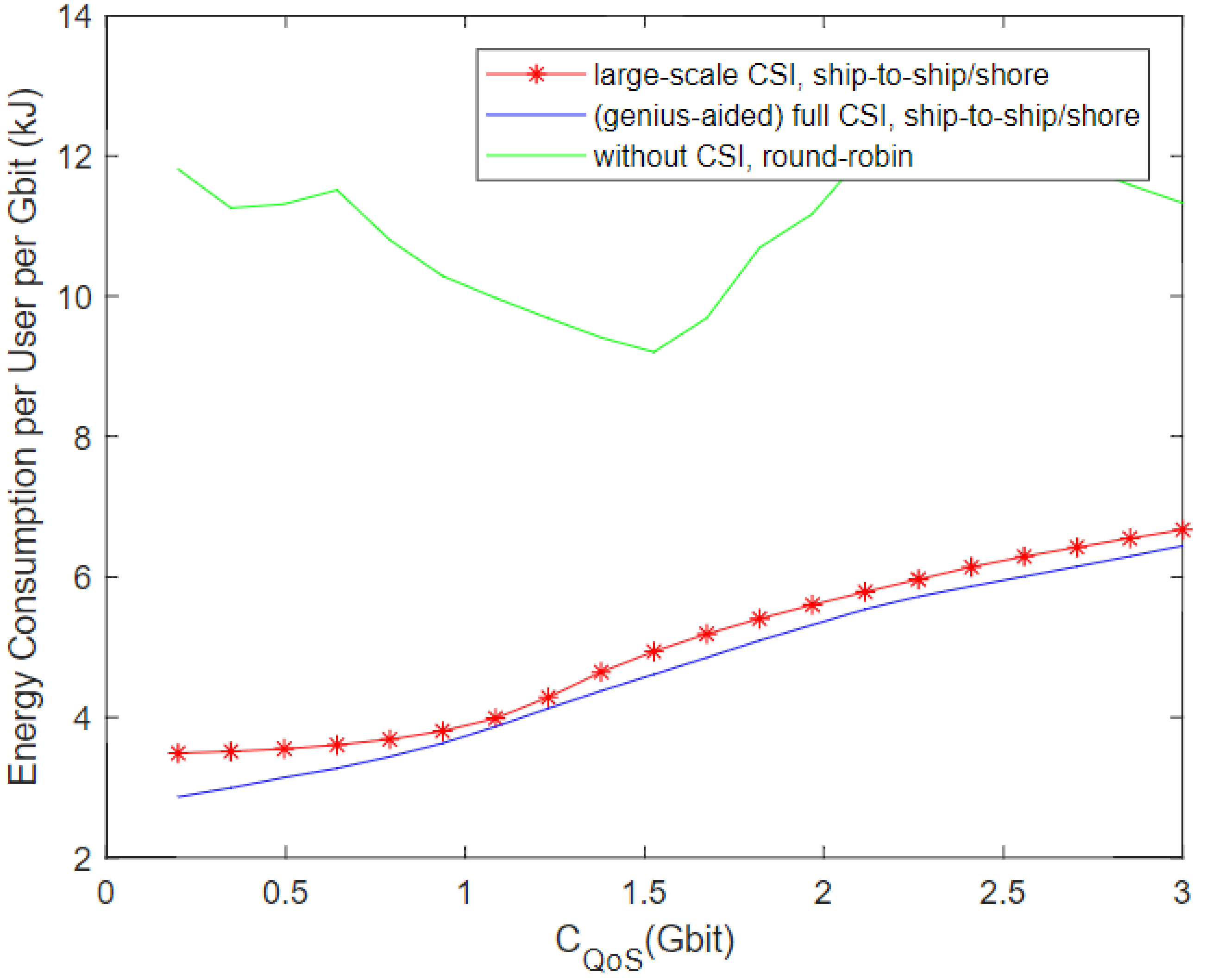
仿真结果

- 可以估计多久未来内的
  - 大尺度信息



仿真结果

- 不同QoS需求影响



仿真结果

- 不同发射功率影响