Adaptive Shipborne Base Station Sleeping Control for Dynamic Broadband Maritime Communications

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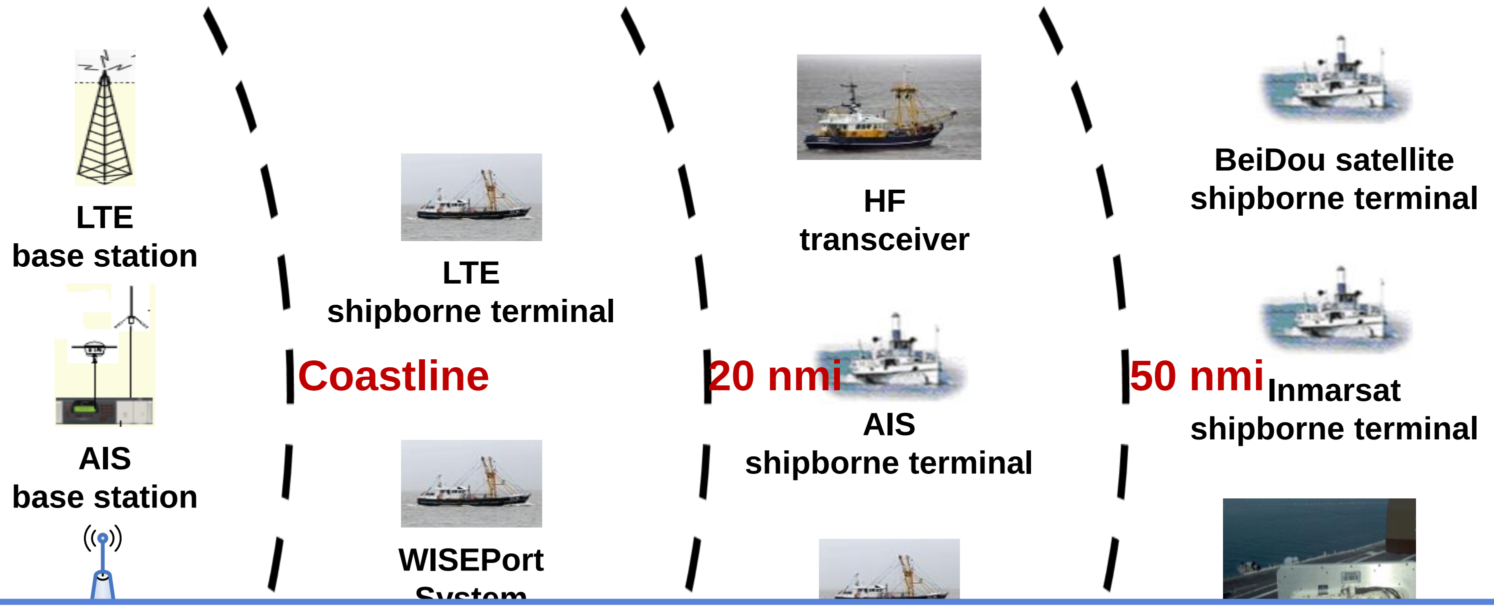
1 Introduction

- **Existing Maritime Communication Systems**

Maritime operation information system

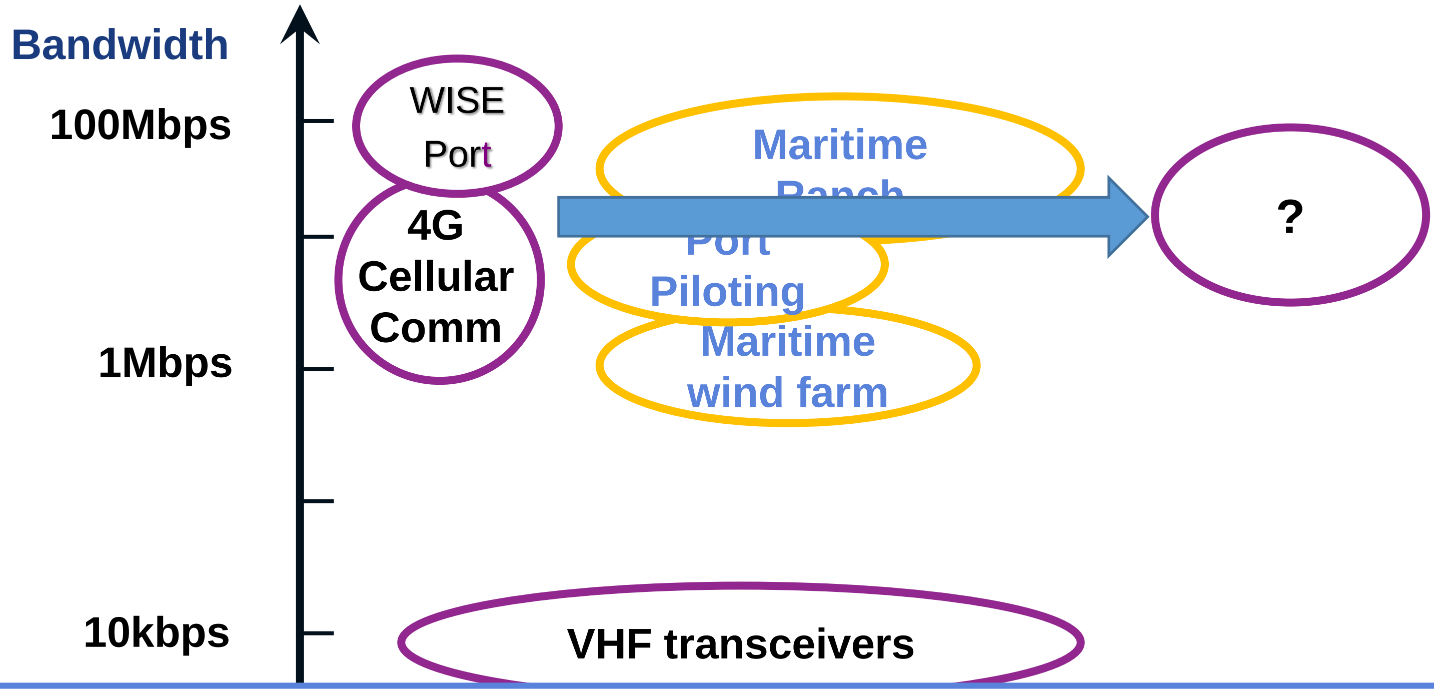
Integrating satellites, CDMA, AIS, VHF, HF, and other means



Satellite : Expensive & Shortage in bandwidth.
LTE: low coverage

1 Introduction

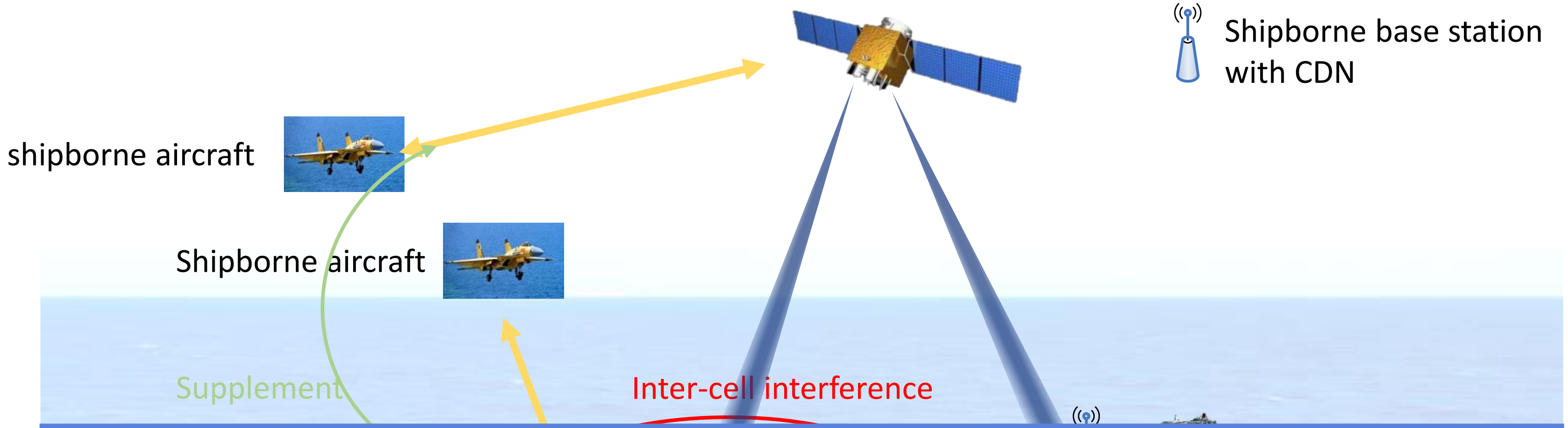
◆ **Challenges in Offshore Areas**



It's effective to expand the terrestrial cellular network to the maritime communication system.

◆ **The BATS System – An example to expand the cellular network**

- **Saving resource from ship-ship communication**
- **Reducing the backhaul need from CDN/cache**

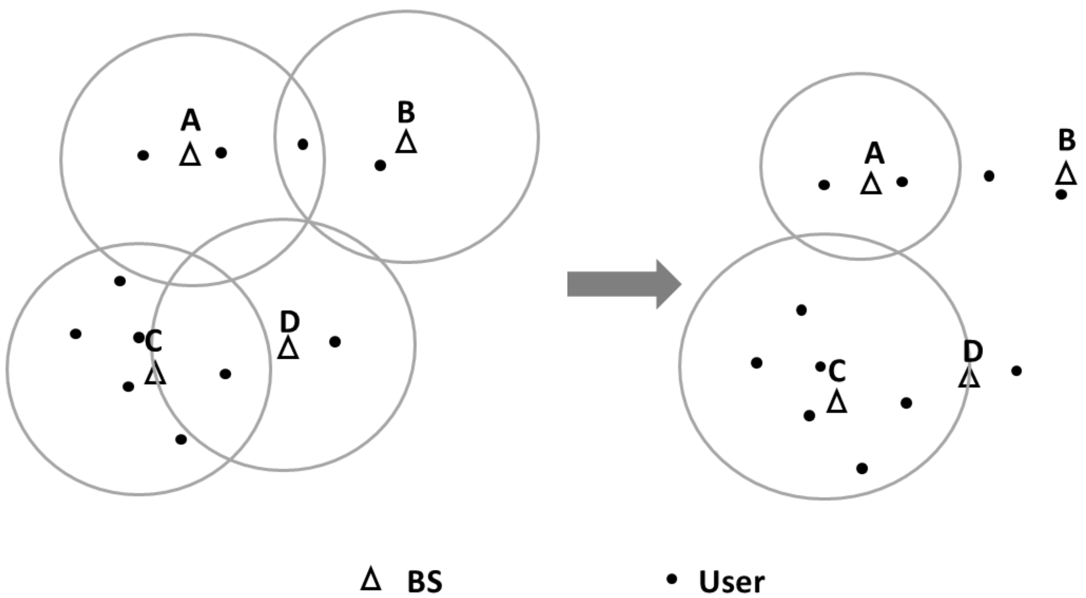


We introduce the base station sleeping control to:
reduce the interference and power comsumption.

1 Introduction

- **The base station sleep control in terrestrial network**

For energy saving and inter-cell interference coordination, it's useful to switch off the base station with low traffic.



B and D are switched off because of the low traffic.

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◆ **A two-part coordinated satellite and terrestrial (II-CST) architecture**

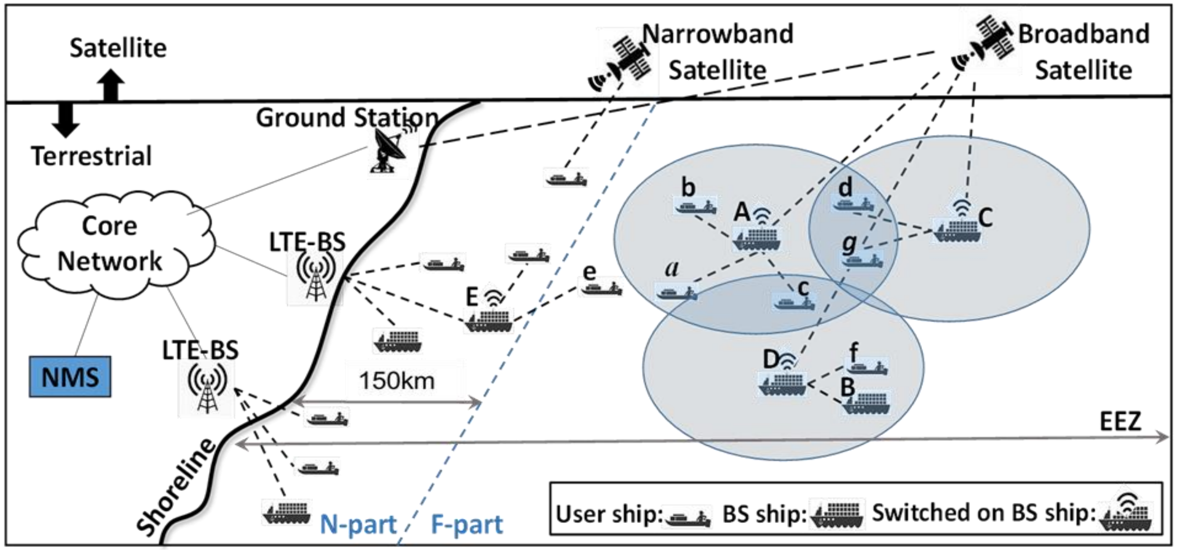

Fig.1 The II-CST architecture for real-time and broadband maritime communications.

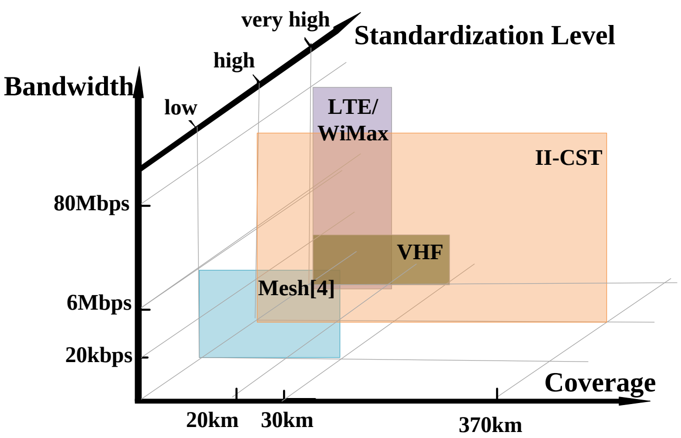

Fig.2 Comparison of 4 different maritime communications

- **Two kinds** of communication ships :
  - **the user ship**: only CPE;
  - **the base station (BS) ship**: the shipborne BS with CDN

- The EEZ is divided into an N-part and a F-part.
  - **N-part**: shipborne BS is served by onshore LTE BS or satellite.
  - **F-part** is beyond the coverage of onshore LTE BSs.

Benefit in bandwidth, coverage and standardization level.

2 Maritime Communication Architecture

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◆ **The Challenge of the proposed architecture**

Radius	E/σ(coverage rate)	Avg(BS ships)
4km	72.52%/0.0164	0.84
8km	90.39%/0.0066	1.67
12km	95.69%/0.0032	3.25

Fig.1 The II-CST architecture for real-time and broadband maritime communications.

TABLE.1 A ROUGH CALCULATION OF II-CST

Radius	E/σ(coverage rate)	Avg(BS ships)
4km	72.52%/0.0164	0.84
8km	90.39%/0.0066	1.67
12km	95.69%/0.0032	3.25

- When the coverage radius of 12km, a user ship can be covered by 3.25 S-BSs. The users are face with a **inter-cell interference problem**.
-

We introduce the base station sleeping control to:
reduce the interference and power comsumption.

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◆ **The Propagation Model**

The two-ray model.

The received power at U_j from its serving S-BS B_i is:

$$P_r(j,i,t) = 10log_{10}(P_t(i,j,t)) - L_{j,i}(t) \qquad (3)$$

Where $L_{j,i}(t)$ is an estimate of the path loss

$$L_{j,i}(t) = -10\log_{10}\left\{\left(\frac{\lambda}{4\pi d_{j,i}(t)}\right)^2 \left[2\sin\left(\frac{2\pi \cdot h_i \cdot h_j}{\lambda d_{j,i}(t)}\right)\right]^2\right\} \qquad (4)$$

TABLE.2 A ROUGH CALCULATION OF II-CST

Symbol	Meaning
N(t)	S-BS number
M(t)	User number
$P_t(i,j,t)$	Transmitting power of B_i
P_{max}	Maximal Transmitting power
uBlock(t)	The blocking user.
$a_i(t)$	Sign of the BS sleeping status.
$s_{j,i}(t)$	Access relationship.

◆ **The Resource Allocation Model**

Equally distribution.

Each B_i has K resource blocks (RBs). If served by B_i, the achievable downlink data rate of U_j is:

$$R(j,i,t) = \frac{Bs}{|S_i(t)|} \cdot log_2\left(1 + \Gamma_{j,i}(t)\right) \qquad (5)$$

Where Bs is the bandwidth of B_i, and $\Gamma_{j,i}(t)$ is the signal to interference noise ratio (SINR) of U_j served by B_i.

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4 BS Sleeping Control

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- **Adaptive S-BS sleeping scheme**

Our adaptive S-BS sleeping scheme has three steps, which is executed in network management system (NMS).

- **Step 1**: **Data Processing**: Collecting ship data in AIS and estimate the ship locations. Calculate the composite received power and user blocking rate. When the proportion of the blocked user ships is beyond the threshold, execute step 2; otherwise, fallback to step 1.
- **Step 2**: **Integer Linear Programming**: Execute an S-BS sleeping approach AS_ILP.
- **Step 3**: **Power Adjustment**: Take the sailing position of accessed user ships as a constraint to adjust the downlink power of S-BSs.

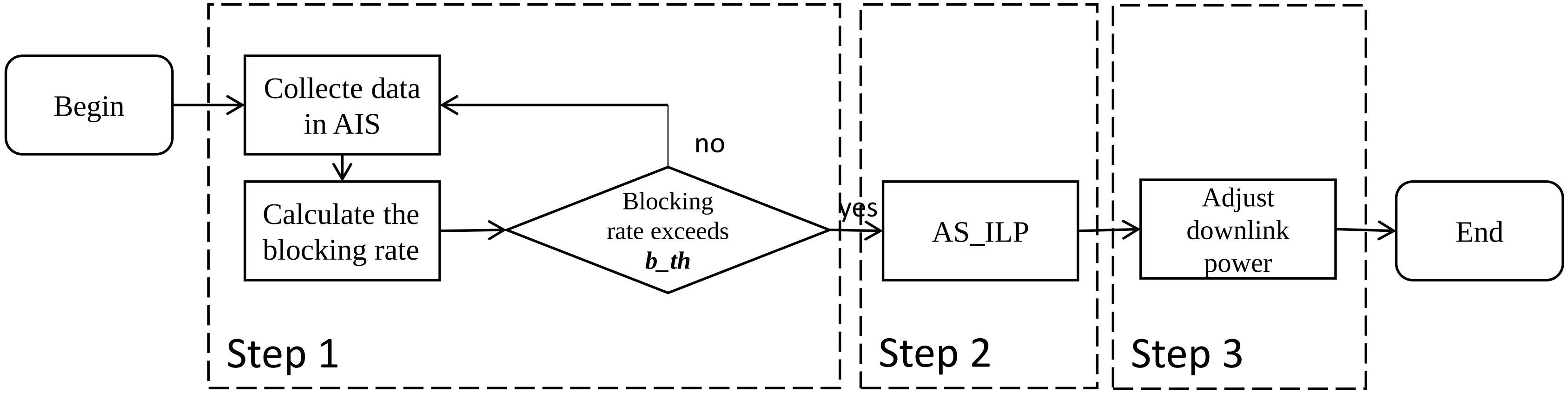

Fig.3 The flow diagram of algorithm.

4 BS Sleeping Control

◆ **Step 1 – Data collecting**

Target: Collect and calculate necessary parameter.

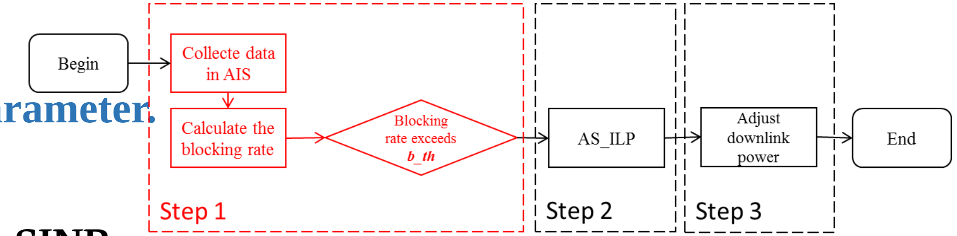

Fig.3 The flow diagram of algorithm - step 1.

➢ **Voyage-based processing**

Due to the mobility of ship, we calculate the SINR:

$$\Gamma_{j,i}(t)=\frac{\alpha P_r(j,i,t)+(-1)^q(1-\alpha)P_r(j,i,t+\tau)}{\sigma^2+\sum_{n=1,n\neq i}^{N}a_n(t)P_r(j,n,t)}\geq\Gamma_{thr},$$

$$\text{where } q=\begin{cases}0, \text{if } d_{j,s}(t+\tau)\geq d_{j,i}(t+\tau)\\ 1, \text{else}\end{cases}.$$

We define the composite power received at U_j from B_i:

$$P_r^C(j,i,t)=\alpha P_r(j,i,t)+(-1)^q(1-\alpha)P_r(j,i,t+\tau)$$

The predicted voyage data.

➢ **Trigger**

When the proportion of the blocked user ships is beyond the threshold, execute step 2; otherwise, fallback to step 1.

Alg. 1 Adaptive Shipborne BS Sleeping Scheme

***f(i)*: the farthest user ship served by B_i^t**
$\Gamma_{th\_f(i)}$: the minimum SINR threshold of *f(i)*
Begin
0: If *|uBlock(t)|/M(t)>b_th then*
1: Set $P_t(i,j,t)=P_{max}$, $\forall i,j$ existing at time *t*
2: Solve AS_ILP and perform the resulting S-BS sleeping and user ship handover plan
3: End if
4: For *i* = 1 to N do
3: If $a_i(t)$=1 then
4: Set *f(i)* =argmax$\{d_{j,i}(t)\ |s_{j,i}(t)=1,\forall j\}$
5: Let $P_r(f(i), i, t+\tau)$ = $P_r(f(i), i, t)$ to compute the new $P_r(f(i),i,t)$ by (6)
6: Compute the new $P_t(i,f(i),t)$ by (3), and adjust $P_t(i,j,t)$ to $P_t(i,f(i),t)$
7: End if
8: End for
End

4 BS Sleeping Control

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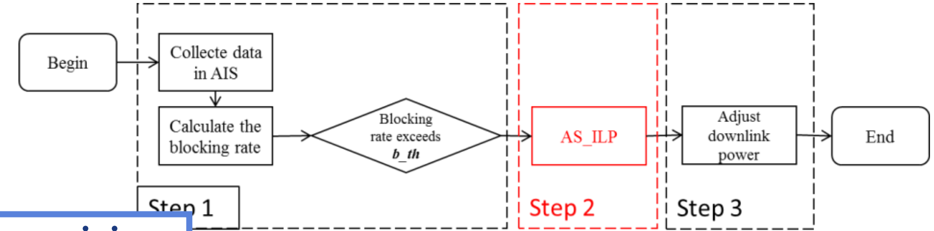
◆ **Step 2 – AS_ILP**

Target: make sure the active shipborne BS and the access BS of users



g.4 The flow diagram of algorithm - step 2.

Minimize the active BS.

Maximize the user receiving power.

Objecti function:

$$\text{Min: } \sum_{i=1}^{N(t)} a_i(t) - \gamma \sum_{j=1}^{M(t)} \sum_{i=1}^{N(t)} s_{j,i}(t)\, P_r^C(j,i,t) \qquad (7)$$

Subject to:

$$a_i(t) P_r^C(j,i,t) - \Gamma_{th\_j} \left[\sigma^2 + \sum_{n=1, n\neq i}^{N(t)} a_n(t) P_r(j,n,t) \right] \geq$$

$$-\Gamma_{th\_j} \left[\sigma^2 + \sum_{n=1, n\neq i}^{N(t)} P_r(j,n,t) \right] \left[1 - s_{j,i}(t) \right], \forall j, i \qquad (8)$$

The SINR constraint.

$$s_{j,i}(t) \leq a_i(t), \forall j, i \qquad (9)$$

$$\sum_{i=1}^{N(t)} s_{j,i}(t) \leq 1, \forall j \qquad (10)$$

User can access only one BS

Alg. 1 Adaptive Shipborne BS Sleeping Scheme

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$\Gamma_{th\_f(i)}$: the minimum SINR threshold of *f(i)*
Begin
0: If |*uBlock(t)*|/*M(t)*>*b_th then*
1: Set $P_t(i,j,t)$=P_{max}, $\forall i,j$ existing at time *t*
2: Solve AS_ILP and perform the resulting S-BS sleeping and user ship handover plan
3: End if
4: For *i* = 1 to N do
3: If $a_i(t)$=1 then
Set *f(i)* =argmax$\{d_{j,i}(t) \mid s_{j,i}(t) = 1, \forall j\}$
5: Let *P*$P_r(f(i), i, t+\tau)$ = $P_r(f(i), i, t)$ to compute the new $P_r(f(i), i, t)$ by (6)
6: Compute the new $P_t(i, f(i), t)$ by (3), and adjust $P_t(i,j,t)$ to $P_t(i, f(i), t)$
7: End if
8: End for

The formulated problem is NP-Complete, and it is exactly similar to the Stochastic Capacitated Facility Location Problem (SCFLP), which is known to be NP-Hard. This problem can be solved in polynomial time.

4 BS Sleeping Control

◆ **Step 3 – Adjust downlink power**

Target: Adjust the transmitting power of every shipborne BS.

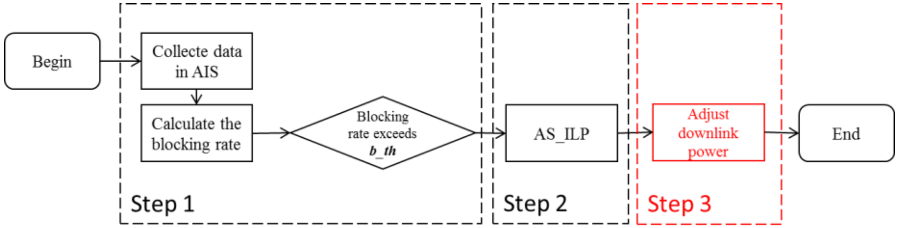

Fig.5 The flow diagram of algorithm - step 3.

For each active S-BS, we find its farthest user ship *f(i)* within coverage, and change its transmitting power to a value that can just meet the minimum SINR threshold of *f(i)*.

Alg. 1 Adaptive Shipborne BS Sleeping Scheme

$f(i)$: the farthest user ship served by B_i^t
$\Gamma_{th\_f(i)}$: the minimum SINR threshold of $f(i)$
Begin
0: If $|uBlock(t)|/M(t) > b\_th$ then
1: Set $P_t(i,j,t)=P_{max}$, $\forall i,j$ existing at time t
2: Solve AS_ILP and perform the resulting S-BS sleeping and user ship handover plan
3: End if
4: For i = 1 to N do
3: If $a_i(t)$=1 then
4: Set $f(i)$ =argmax$\{d_{j,i}(t) \mid s_{j,i}(t) = 1, \forall j\}$
5: Let $P_r(f(i), i, t+\tau) = P_r(f(i), i, t)$ to compute the new $P_r(f(i), i, t)$ by (6)
6: Compute the new $P_t(i, f(i), t)$ by (3), and adjust $P_t(i,j,t)$ to $P_t(i, f(i), t)$
7: End if
8: End for
End

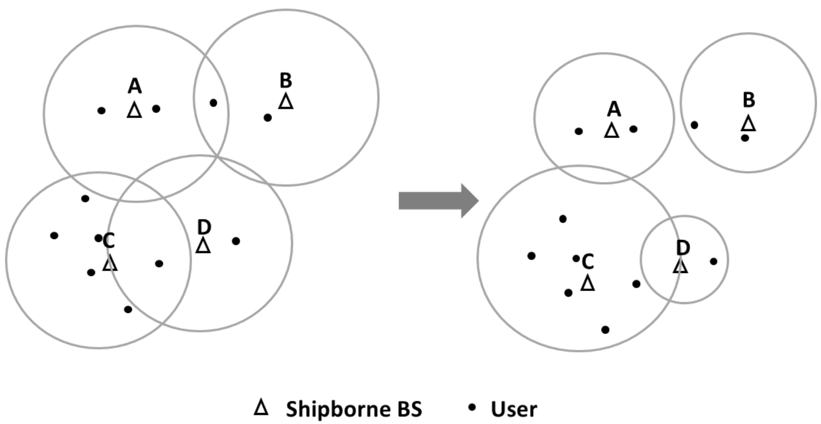

Fig.3 The sketch map of power adjustment.

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1 Introduction

2 Maritime Communication Architecture

3 System Model

4 BS Sleeping Control

5 Simulation

6 Conclusions

5 Simulation

◆ Simulation Environment

Fig. 5 shows the region of interest (an area framed by red lines in China's Yellow Sea). We take 60 days of good ship voyage data D_{60}(Apr. 1-30 and Oct. 2-31, 2015) within this region. The raw data is processed as follows:

1) **Data completion**: D_{60} is divided by every 3 minutes, and we complete the data by interpolation if AIS records of any ship within an hour is beyond 3 minutes.

2) **Ship type**: We take passenger vessels, cargo vessels and tankers as BS ships and the others as user ships, mark the ship type.

The performance is evaluated by **MATLAB**.

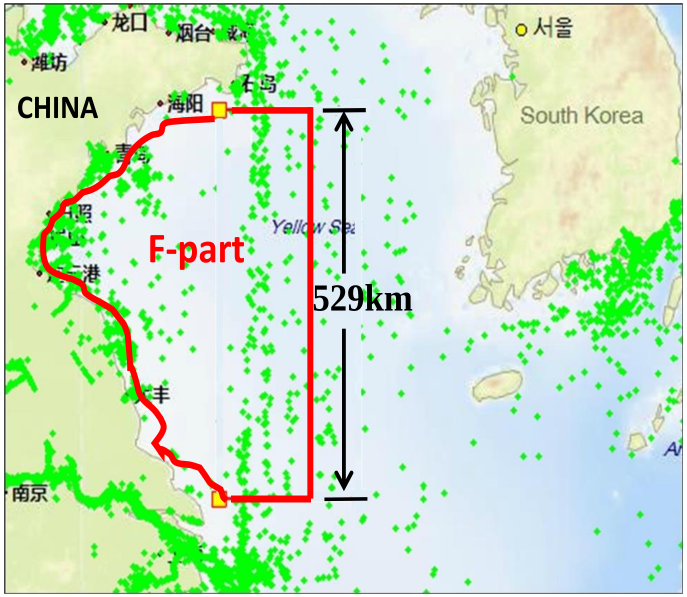


Fig.3 The flow diagram of algorithm - step 1.

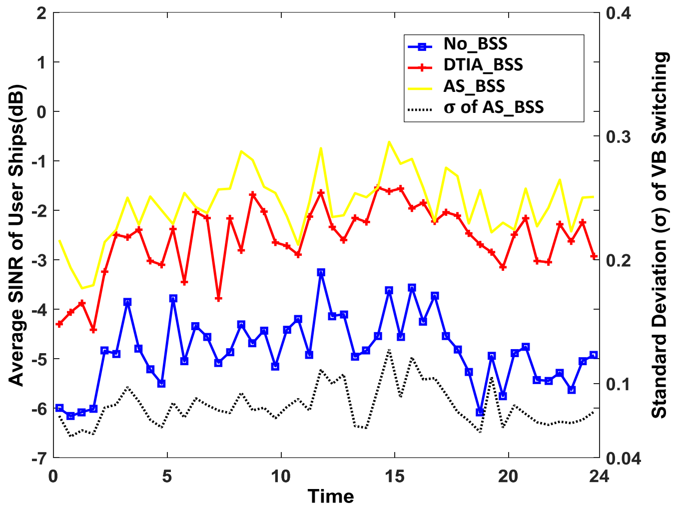
TABLE.3 SIMULATION PARAMETER

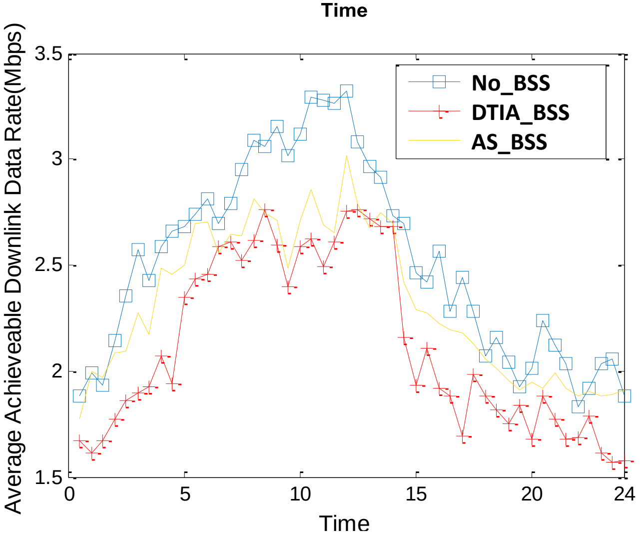
Parameters	Value
Maximum transmitting Power (P_{max})	20w
Carrier frequency	1.89GHz
Height of S-BSs	35m
Height of user ships	15m
Maximum users (U_{max})	40
Threshold of blocked users (b_th)	0.08
τ in formula (6)	15min
α in formula (6)	0.8
Γ_{th_j} in formula (6)	-5db
γ in formula (7)	1E8

1. S. A. Alam, S. L. Dooley, and S. A. Poulton, "Traffic-and-interference aware base station switching for green cellular networks," in *Proc* IEEE 18th International Workshop on Computer Aided Modeling and Design of Communication Links and Networks (CAMAD), Sep. 2013, pp. 63-67.

5 Simulation

◆ **SINR and Downlink Data Rate of User Ships**





➢ **User SINR**

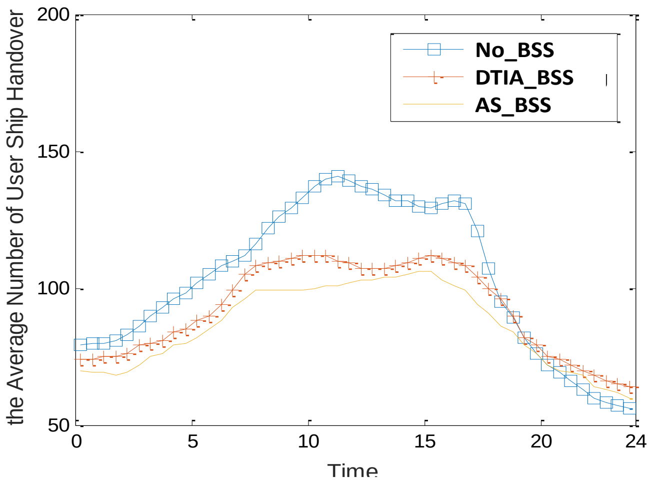
- AS_BSS scheme can effectively improve the average SINR of user ships compared with DTIA_BSS.
- AS_BSS is better in downsizing the dynamically overlapped coverage of S-BSs, which helps to improve the average SINR of user ships.

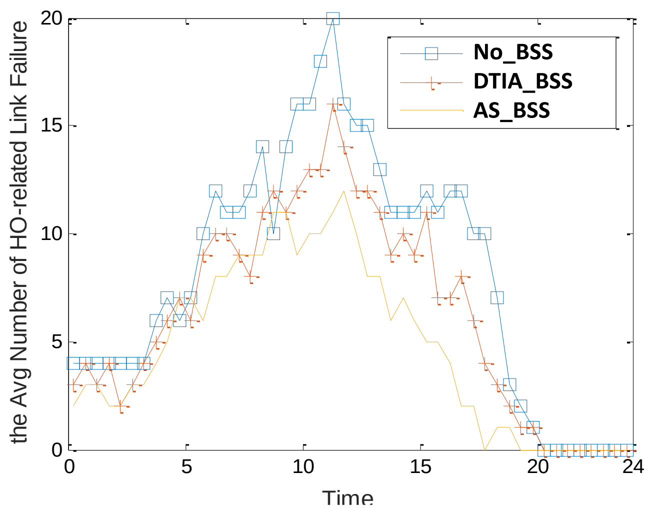
➢ **Downlink Data Rate**

- Due to the reduction of bandwidth resource, the data rate is reduced compared with NO_BSS.
- AS_BSS can switch the proper S-BSs to on/doze state to recover the blocked user ships, which can reduce the ICI, improve the highest date rate.

5 Simulation

◆ **The Number of Handover and HO-related link failures**





➢ **Handover Number**

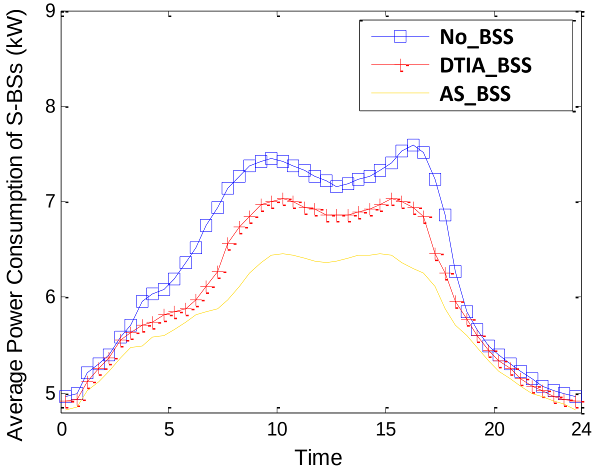
- . AS_BSS uses the voyage-based data to calculate SINR, which allows user ships to choose the similar direction ship as the access point.
- However, sleeping schemes may have little influence on the handover.

➢ **HO-related Link Failures**

- AS_BSS has less HO-related radio link failures than DTIA_BSS in most cases, which can effectively enhance the mobility robustness of the user ships.
- Besides, the consideration of future sailing status also helps to avoid HO-related link failures. In Fig. 4(a),

5 Simulation

◆ The Power Consumption



➢ Power Consumption

- . AS_ILP enables a more rational distribution of active S-BSs from a global view, which helps to reduce the number of active S-BSs.
- After executing the S-BS sleeping plan, the transmitting power adjustment further reduces the power consumption of active S-BSs.

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6 Conclusions

1. This paper has investigated the solutions for real-time broadband maritime communication and the BS sleeping schemes for terrestrial networks. A two-part radio access networking for the EEZ is presented to provide real-time and affordable broadband access.

2. An adaptive shipborne BS sleeping scheme is proposed to dynamically coordinate inter-cell interference, improve mobility robustness, and reduce system power consumption. Simulation results validated the effectiveness of our adaptive sleeping scheme.

Thank you!