Hindawi
Mobile Information Systems
Volume 2022, Article ID 8678007, 11 pages
https://doi.org/10.1155/2022/8678007

Research Article

Cooperative Multi-Path Routing Algorithm for Integrated Satellite-Maritime Networks

Sungwook Kim

Department of Computer Science, Sogang University, 35 Baekbeom-ro (Sinsu-dong), Mapo-gu, Seoul 04107, Republic of Korea

Correspondence should be addressed to Sungwook Kim; swkim01@sogang.ac.kr

Received 13 May 2022; Revised 13 August 2022; Accepted 8 September 2022; Published 18 October 2022

Academic Editor: Ramon Aguero

Recent advances in wireless communication technologies have allowed mobile users to access various data services anytime and anywhere. In this study, we focused on an integrated satellite-maritime network (ISMN) platform to develop a novel multipath routing scheme. By considering the geographic features of the sea and different data types, we adopted coalitional game theory to design new routing algorithms in the ISMN infrastructure. According to the concepts of different value solutions, routing packets are adaptively distributed into multiple routing paths while self-adjusting to widely diversified ISMN system situations. Therefore, the mutual benefits accrued from cooperation can be explored while leveraging reciprocal consensus between different routing control issues. The simulation results demonstrate that the proposed scheme fits well with the ISMN platform using our coalitional game-based approach.

1. Introduction

Recently, fifth-generation (5G) wireless communication networks have been standardized and deployed worldwide. The major goals of 5G networks are ultrareliable and low-latency communication. Various key technologies have been proposed to achieve the 5G goals. However, 5G networks will not meet all the requirements of the future world; 5G networks are still limited in accessing remote areas. Nowadays, researchers in academia and industry have started to focus on sixth-generation (6G) wireless communication networks. One of the main distinguishing features of the 6G agenda is that it provides nearly 100% geographical coverage with massive connectivity. This connected global scenario must ensure worldwide coverage. Therefore, human activities will expand dramatically from space to air, ground, and sea environment in this era. To ensure worldwide wireless connectivity in future networks, it is necessary to integrate multi-dimensional space-air-ground-sea networks, which play important roles in 6G communications, especially in remote areas [1, 2].

The ocean area accounts for more than 70% of the Earth's area, and more than 80% of the world's cargo transportation is completed by ocean shipping. At the same time, many maritime activities remain essential to the economy and society, with high expectations for future growth. Therefore, it is increasingly important to provide wireless broadband services at sea, connecting various types of maritime agents, such as ships, maritime buoys, oil drilling rigs, and beacons. Maritime ad-hoc networks (MANETs) are wireless multi-hop networks comprised of maritime agents that establish connections among themselves and with a chain of shore backhaul stations along the coastlines. With the development of technologies, maritime agents need to be facilitated through effective communications and services in any sea area. Therefore, MANETs provide various data services to deploy and support maritime communication, navigation, and emergency response with satisfactory quality of service (QoS) [3, 4].

Establishing a secure and successful maritime network system is significantly challenging owing to the distinctive environment of MANETs and the presence of heterogeneous types of services. For the state-of-the-art maritime communications, different communication networks can be constructed, including self-assembling MANETs using ad-hoc technology and satellite networks for wide-area coverage. Therefore, hybrid network infrastructure has emerged in which satellites and maritime networks are integrated to enhance maritime coverage while satisfying the increasing requirements of different services. However, satellite communication is not cost-effective. For the ever-increasing level of data traffic in the ocean, it is still quite challenging to realize global broadband coverage using satellite technologies at a practically affordable cost [5, 6].

In this study, we focused on an integrated satellite-maritime network (ISMN) platform. Maritime and satellite networks can work together and cooperatively provide data services to maritime users. Owing to the broad ocean area and diversity of required contents, the ISMN infrastructure may be concluded to provide the best compromise. Routing is very important for adaptive and efficient ISMN operations. Usually, network performance is strongly related to the routing algorithms. In the routing mechanism, network administrators should decide how certain types of traffic are to be treated by network agents. There are two general categories of network traffic: real-time and non-real-time data traffic. Real-time (RT) traffic services are important and time-critical; they must be delivered on time and with the highest quality possible. Therefore, timeliness is the primary measure of accuracy. Non-real-time (NRT) traffic services mainly concern good average-case performance while tolerating a slow response time. Therefore, time constraints have not been seriously considered [7, 8].

Motivated by the above discussion, we developed a novel routing scheme for an ISMN platform. Owing to the characteristics of the ISMN topology, the proposed scheme establishes multiple paths and adaptively distributes routing packets through these paths. Although some excellent researches have been conducted on multipath routing issues, the development of ISMN routing is still in its infancy. In practice, the optimal distribution of different types of traffic data still faces several challenges. To implement our data distribution algorithm, we should consider the service data type and give a higher priority to the RT services based on the current network conditions.

The remainder of this paper is organized as follows. In Section 2, we provide the preliminary concept of cooperation game theory, which is adopted to design our ISMN multipath routing scheme. In Section 3, related research articles that have drawn our attention are summarized. Section 4 explains the ISMN infrastructure and routing data distribution problem. Then, we introduce the basic ideas of cooperative game solutions. Based on our three-phase coalitional game approach, the details of our proposed scheme are discussed in this section. In Section 5, we discuss our simulation setup and provide a numerical analysis while comparing the performance of the proposed scheme with other existing schemes. Finally, Section 6 concludes this study, and future research directions and issues are summarized on the basis of our conclusions.

2. Technical Concepts and Main Contributions

In particular, operations contending for multipath network resources rely on the cooperation of each network agent. Therefore, cooperation game theory is an attractive idea for designing our ISMN multipath routing scheme. Game theory is the study of mathematical models of strategic interaction among rational decision-makers, and it provides useful tools for studying distributed optimization problems. Originally, game theory was a theoretical framework for conceiving social situations among competing game players. In some respects, game theory is the science of strategy, or at least the optimal decision-making of independent and competing players in a strategic setting. As one of the two counterparts of game theory, coalitional game theory studies the interactions among coalitions of players and provides what payoff will be awarded to each player, and the evaluation of players' expectations is given by a coalitional value [9, 10].

A pioneering idea that addresses the coalitional game is the *Shapley value*, which is based on two main assumptions: (i) a player who joins a coalition obtains the whole of his marginal contribution and (ii) all players enjoy an equal chance of joining any given coalition being constituted. It is usually viewed as a good normative answer to the questions posed in coalitional game theory. As another solution, the *solidarity value* agrees with the idea of the *Shapley value* regarding the principle of equal opportunity of admission into any given coalition, except that the contribution of a player to a coalition is replaced by the average contribution of the coalition's members. Therefore, because every coalition can be formed, each player receives the average marginal contribution of a member of the formed coalition [9, 10].

If coalitional value solutions are considered from an axiomatic perspective, asymmetric versions of existing value solutions appear when the property of *symmetry* is dropped from the set of axioms that characterize the value. Asymmetric value solutions could be differences in the negotiation ability of players while endowing weights to values to balance the relationship between utilitarianism and egalitarianism. Therefore, it seems more realistic to introduce weights associated with players to measure these differences. Recently, the *weighted Shapley value* (*WSV*) and *weighted solidarity value* (*WSoV*) have been proposed with the concept of the weighted sum of the average contributions of different players. In addition, the *weighted surplus division value* (*WSdV*) is presented as a new distribution rule for marginal contributions. The *WSdV* is similar to the philosophical idea of the *Shapley value*, but it focuses on how the marginal contributions are divided among the predecessors and considers the exogenous weights when distributing the surplus portion after every player takes his individual worth [11, 12].

Based on the *WSV*, *WSoV*, and *WSdV* solutions, we can effectively solve the data distribution problems in the ISMN routing algorithm. By considering different preferences for RT and NRT data services, we designed a novel three-phase coalitional game model. In the first phase, the RT data is divided into two parts for satellite and MANET communications. In the second phase, the RT data, which are assigned to the MANET, was distributed into multiple paths. In the third phase, the NRT data is distributed into multiple paths in the MANET. For the control decisions at each phase, the ideas of *WSdV*, *WSV*, and *WSoV* are applied individually. During the interactive and iterative processes, we appropriately handle the data distribution problem in the ISMN infrastructure, leading to an optimized system performance. The major contributions of this study are summarized as follows:

(i) We studied the fundamental concepts of *WSV*, *WSoV*, and *WSdV* solutions to design our multipath routing algorithm. Based on the main characteristics of the ISMN platform, we formulated three different coalitional game models to support the RT and NRT data services.

(ii) In the first phase, the RT data amount is divided by using the idea of *WSdV*; one part is assigned to the satellite network communication, and the other part is allocated for the MANET communication.

(iii) In the second phase, the RT data allocated to the MANET is dynamically distributed into multiple paths, which are established in an ad-hoc manner. The data distribution process is designed according to the *WSV* solution.

(iv) In the third phase, the NRT data is distributed into multiple paths in the MANET. By considering the features of NRT data services, the concept of the *WSoV* solution was adopted to obtain a desirable solution.

(v) Based on the iterative combination of three-phase processes, we leverage a reciprocal consensus for different RT and NRT data services in a coordinated manner while adapting to dynamic ISMN situations.

(vi) Extensive simulations were carried out to gain insight into the maritime data communication problem, and verify the effectiveness of the proposed approach. According to the numerical analysis, we compare the performance of our scheme with the existing maritime routing protocols, and demonstrate that the proposed cooperative approach fits well with the ISMN platform.

3. Related Work

Current research literature on next-generation maritime networks is struggling with the aim of 6G, where the integration of satellite-maritime networks is looking like a future. In the paper [13], two routing algorithms based on the ad hoc on-demand multipath distance vector approach are investigated. According to the issue of energy efficiency, backbone formation is made for preserving the node energy. The goal of this method is the determination of the actual degree of the energy constraint for the dominating set of nodes for the extension of the lifetime of the network. In [14], Y. Wang et al. established a hierarchical network system and proposed the *Satellite Maritime Ubiquitous Coverage* (*SMUC*) scheme for maritime coverage enhancement by utilizing, (i) satellites for global signaling, (ii) on-shore base stations for sending source data, and (iii) some vessels for opportunistically relaying data. By exploiting extrinsic information, all network agents are orchestrated in a process-oriented manner. Based on this hybrid network platform, they mathematically formulated a joint scheduling and rate adaptation problem while providing QoS guarantees. To optimize this problem, an efficient iterative solution is proposed by leveraging relaxation, and a novel gradually approaching method is also designed based on the gentlest ascent principle and min-max transformation. With polynomial computation complexity, the *SMUC* scheme ensures a viable solution for resource-limited practical maritime data communications. Simulation results show that the *SMUC* scheme can achieve a performance close to that of the optimal solution [14].

In [2], the next-generation integrated space-oceanic network, which consists of satellite and maritime networks, was proposed as the *Integrated Network Profit Maximization* (*INPM*) scheme for this platform. To maximize network profit in the integrated network infrastructure, the *INPM* scheme formulates a joint maritime user association and resource allocation problem. The formulated optimization problem corresponds to mixed-integer nonlinear programming, and this problem is solved using an iterative algorithm based on Bender's decomposition, which is the best fit for integer variables. From the viewpoint of satellites, the *INPM* scheme provides optimal user association and resource allocation algorithms. Finally, the numerical results are presented to demonstrate the convergence and effectiveness of the *INPM* scheme [2].

The *Multi Radio and Channel Assignment* (*MRCA*) scheme in [15] presents a modified particle swarm optimization technology for a mesh network platform, which is envisaged for maritime communications because of its expanded coverage, self-healing, and high capacity. Therefore, wireless mesh networks could be promising architectures for maritime networks. However, these are still challenging limitations. The major challenge is the channel assignment between communication links that transmit data. The *MRCA* scheme focuses on the static channel assignment issue and proposes a heuristic algorithm to solve the channel control problem. This approach provides a multi-dimensional view of the challenges in maritime data communications while considering system dynamics. Finally, the advantage of the *MRCA* scheme was demonstrated by comparing the packet delivery ratio with different existing algorithms [15].

To date, some protocols for maritime data communications have been proposed with novel ideas and methodologies. Instead of the existing methods, the main challenge of our approach lies in efficient data distribution with the *WSV*, *WSoV*, and *WSdV* solutions. To the best of our knowledge, this is the first study that jointly considers multiple value solutions to distribute routing packets through multiple paths in the ISMN platform.

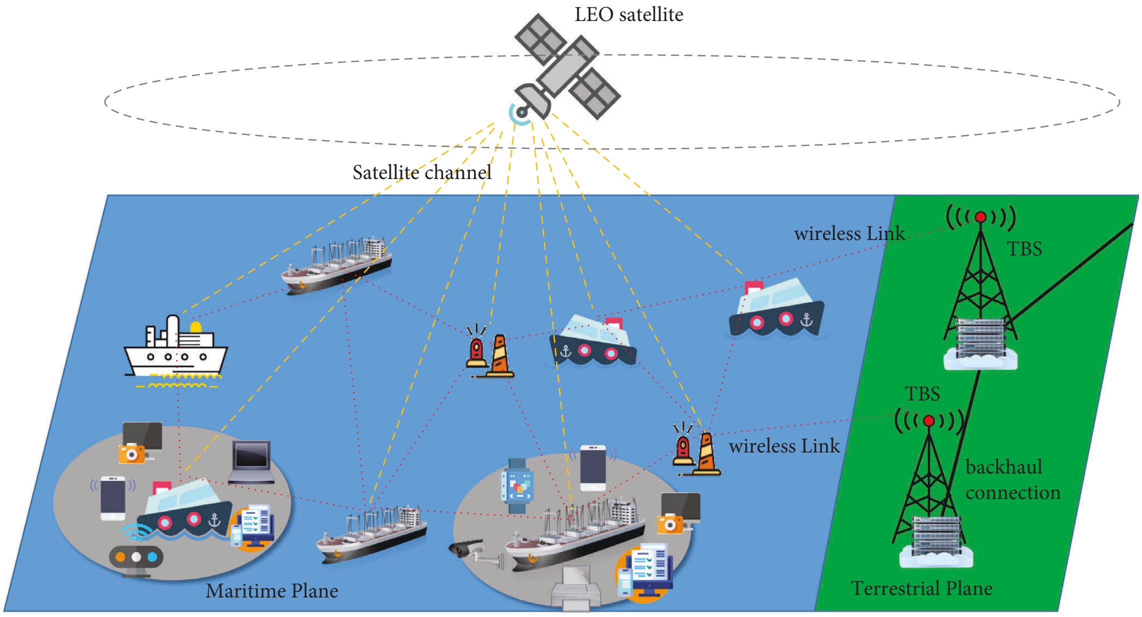


Figure 1: The overview of ISMN system platform.

Table 1: The notations for abbreviations, symbols, and parameters.

Acronym	Explanations
ISMN	Integrated satellite-maritime network
5G	Fifth-generation
6G	Sixth-generation
MANET	Maritime ad-hoc networks
QoS	Quality of service
RT	Real-time
NRT	Non-real-time
WSV	Weighted shapley value
WSoV	Weighted solidarity value
WSdV	Weighted surplus division value
SMUC	Satellite-maritime ubiquitous coverage
INPM	Integrated network profit maximization
MRCA	Multi radio and channel assignment
TBSs	Terrestrial base stations
LOS	Line-of-sight
LEO	Low Earth orbit
MUDs	Marine user devices
ED	Equal division
AODV	Ad hoc on-demand distance victor

4. The Proposed Data Distribution Scheme in the ISMN

In this section, we introduce the ISMN system infrastructure and explain the three-level coalitional game model for our maritime data distribution algorithm. Then, the main ideas of the *WSV*, *WSoV,* and *WSdV* solutions are presented to design the proposed ISMN routing scheme. Finally, we explain the main steps of our coalitional game-based approach.

4.1. ISMN Infrastructure and Three-phase Coalitional Game Model. In this study, we assumed a practical hybrid ISMN infrastructure consisting of maritime ships, buoys, low Earth orbit (LEO) satellites, and terrestrial base stations (TBSs) as shown in Figure 1, and Table 1 lists the notations used in this paper. TBSs can be deployed along the coast to offer high-rate backhaul communications. To enable remote access, the LEO satellite is a suitable candidate for addressing maritime network challenges. It can fulfill QoS demands owing to its line-of-sight (LOS) nature, which makes it practical for our scenario. Moreover, we assumed that the LEO satellite has a backhaul connection with the Earth gateway or TBSs. Maritime ships and buoys can establish connections to form a wireless multi-hop network while integrating satellite communication. Therefore, maritime users can reach the TBS via (i) other ships or buoys through multiple hops, or (ii) the LEO satellite. The multi-hop nature of the ISMN provides a pooling platform so that network agents' resources, wireless services, and satellite communications can be shared by maritime users [2, 4].

Our network topology has a set $\boldsymbol{\mathcal{S}} = \{\mathcal{S}_1, \ldots \mathcal{S}_n\}$ of ships on the sea, and a set $\mathfrak{B} = \{\mathcal{B}_1, \ldots \mathcal{B}_m\}$ of floating buoys. Each $\mathcal{S}_{1\le i\le n}$ has multiple marine user devices (MUDs) denoted by $\mathbb{D}^{\mathcal{S}_i} = \left\{\mathcal{D}_1^{\mathcal{S}_i}, \ldots \mathcal{D}_k^{\mathcal{S}_i}\right\}$. We consider that one LEO satellite is optimally deployed at the desired location while fulfilling maritime network demands. Each ship and buoy has a transceiver with a high-gain antenna, which can collect and retransmit data from/to neighboring network agents. Therefore, MANET provides maritime data communication services through multipath routing routes, which are established in an ad-hoc manner. Using agent-borne antennas, data can be transmitted or relayed in a multi-hop manner, which can be deployed flexibly while reducing the cost of communication infrastructure [15].

QoS provision has become an increasingly important and challenging topic in routing mechanisms. In particular, providing the preference for RT data services is important, because the demand for RT data communications in maritime networks has grown rapidly and its quality severely depends on its delay time. In this study, we assumed that each individual MUD generates diversified RT and NRT data services. In this context, we should consider how to differentiate between these services while striking an appropriate system performance. To solve this problem, we developed a three-phase coalitional game model ($\mathbb{G}$), which consists of RT and NRT service processes to share the ISMN system communication resources. In the first and second phase games ($\mathbb{G}_{RT}^{F}$ and $\mathbb{G}_{RT}^{S}$), the RT data packets are divided and distributed. In the third-phase game ($\mathbb{G}_{NRT}^{T}$), the NRT data packets are allocated to multiple paths of MANET. In an interactive and sequential manner, $\mathbb{G}_{RT}^{F}$, $\mathbb{G}_{RT}^{S}$, and $\mathbb{G}_{NRT}^{T}$ act independently and make decisions toward an appropriate ISMN system performance. Formally, we define our three-phase coalitional game entities, that is, $\mathbb{G} = \left\{\mathbb{G}_{RT}^{F}, \mathbb{G}_{RT}^{S}, \mathbb{G}_{NRT}^{T}\right\} = \left\{\left\{\mathbb{G}_{RT}^{F} | \mathfrak{M}_{RT}, \mathscr{W}, \mathscr{X}, \mathscr{U}_{\mathscr{W}}^{RT}, \mathscr{U}_{\mathscr{X}}^{RT}\right\}, \left\{\mathbb{G}_{RT}^{S} | \mathfrak{M}_{RT}^{\mathscr{X}}, \mathbb{P}, \mathbb{U}_{P}^{RT}\right\}, \left\{\mathbb{G}_{NRT}^{T} | \mathfrak{M}_{NRT}^{\mathscr{X}}, \mathbb{P}, \mathfrak{U}_{P}^{NRT}\right\}, T\right\}$:

(i) Our three-phase game $\mathbb{G}$ consists of $\mathbb{G}_{RT}^{F}$, $\mathbb{G}_{RT}^{S}$, and $\mathbb{G}_{NRT}^{T}$; which are mutually and reciprocally interdependent in an interactive manner.

(ii) In the $\mathbb{G}_{RT}^{F}$, $\mathfrak{M}_{RT}$ is the total RT data packets generated from the source agent. $\mathscr{W}$ is the satellite connection path, and $\mathscr{X}$ represents all possible MANET paths.

(iii) The $\mathfrak{M}_{RT}$ is divided into the $\mathscr{W}$ and $\mathscr{X}$. $\mathfrak{M}_{RT}^{\mathscr{W}}$ is the allocated for the $\mathscr{W}$, and $\mathfrak{M}_{RT}^{\mathscr{X}}$ is the allocated to the $\mathscr{X}$ where $\mathfrak{M}_{RT} = \mathfrak{M}_{RT}^{\mathscr{W}} + \mathfrak{M}_{RT}^{\mathscr{X}}$.

(iv) In the $\mathbb{G}_{RT}^{F}$, the $\mathscr{W}$ and $\mathscr{X}$ are game players, and $\mathscr{U}_{\mathscr{W}}^{RT}$ and $\mathscr{U}_{\mathscr{X}}^{RT}$ are their utility functions, respectively.

(v) In the $\mathbb{G}_{RT}^{S}$, $\mathbb{P} = \left\{P_1 \dots P_q\right\}$ represents the set of selected paths in the MANET from the source to the destination agents.

(vi) In the $\mathbb{G}_{RT}^{S}$, $P_{1\leq i\leq q} \in \mathbb{P}$ is a game player, and $\mathbb{U}_{P_i}^{RT}$ is his utility function; $\mathfrak{M}_{RT}^{\mathscr{X}}$ is distributed into multiple paths in $\mathbb{P}$.

(vii) In the $\mathbb{G}_{NRT}^{T}$, $\mathfrak{M}_{NRT}^{\mathscr{X}}$ is the number of generated NRT data packets. $P_{1\leq i\leq q} \in \mathbb{P}$ is a game player, and $\mathfrak{U}_{P_i}^{NRT}$ is his utility function.

(viii) In the $\mathbb{G}_{NRT}^{T}$, $\mathfrak{M}_{NRT}^{\mathscr{X}}$ is also distributed into multiple paths in $\mathbb{P}$ like to the $\mathbb{G}_{RT}^{S}$.

(ix) $T = \left\{t_1, \dots, t_c, t_{c+1}, \dots\right\}$ denotes the time period, which is represented by a sequence of time steps.

4.2. *The Basic Idea and Implementation of Value Solutions.*

To characterize the basic concepts of value solutions, we begin with some definitions. A coalitional game on a finite player set $N = \{1 \dots i \dots n\}$ is an ordered pair (N, v), where utility function $v\colon 2^N \longrightarrow \mathbb{R}$ assigns to each coalition $S \in 2^N$ as the worth $v(S)$, satisfying $v(\varnothing) = 0$. For each coalition S, $v(S)$ represents the reward that coalition S can be guaranteed by just itself without the collaboration of others. A value is a function γ which assigns to every game (N, v). For each player $i \in N$, (a) real number $\gamma_i(N, v)$ represents an assessment made by the player i; it is his gain from participating in the game. For all $S \subseteq N$ and all $i \in S$, the marginal contribution of player i to coalition S is denoted as $\Delta^i(v, S)$, and let $\Gamma(v, S)$ be the average marginal contribution of all players in the coalition S; they are given by [10–12]

$$\begin{cases} \Delta^i(v, S) = v(S) - v\left(\dfrac{S}{i}\right), \\[2ex] \Gamma(v, S) = \dfrac{1}{|S|} \times \left(\displaystyle\sum_{i\in S} \left(v(S) - v\left(\dfrac{S}{i}\right)\right)\right). \end{cases} \tag{1}$$

According to (1), the player i's *Shapley value* ($Sh_i(\cdot)$) and *Solidarity value* ($So_i(\cdot)$) are defined as follows [10–12]:

$$\begin{cases} Sh_i(N, v) = \displaystyle\sum_{S\subseteq N; i\in S} \left(\dfrac{(n-s)!\,(s-1)!}{n!} \times \Delta^i(v, S)\right), \\[3ex] So_i(N, v) = \displaystyle\sum_{S\subseteq N; i\in S} \left(\dfrac{(n-s)!\,(s-1)!}{n!} \times \Gamma(v, S)\right). \end{cases} \tag{2}$$

As a new viewpoint of Harsanyi, we can define the *Shapley value* differently. The *Harsanyi dividend* identifies the surplus created by a coalition of players in a coalitional game. To specify this surplus, the worth of this coalition is corrected by the surplus created by subcoalitions. To this end, the *Harsanyi dividend* of coalition N in game v ($d_v(N)$) is recursively determined by $d_v(N) = v(N) - \sum_{S\subset N} d_v(S)$. Using the *Harsanyi dividend*, the $Sh_i(\cdot)$ can be redefined as follows [16, 17]:

$$Sh_i(N, v) = \sum_{S\subseteq N; i\in S} \left(\frac{1}{|s|} \times d_v(s)\right). \tag{3}$$

According to (3), we can think that the *Shapley value* allocates the payoff based on players' productivity and gives everyone his expected marginal contribution, presuming that all permutations of players' entrances are equal. In order to account for asymmetries among players beyond the game, the *weighted Shapley value* (WSV) was proposed, where these asymmetries are modeled by weights, which are explicitly given to players. With the weight vector $\omega \in \mathbb{R}_{++}^{N}$, the player i's WSV ($WSV_i^{\omega}(\cdot)$) is defined as follows [16, 17]:

$$\begin{gathered} WSV_i^{\omega}(N, v) = \sum_{S\subseteq N; i\in S} \left(\frac{\omega_i}{\sum_{j\in S}(\omega_j)} \times d_v(s)\right), \\ \text{s.t.}, i \in N, \omega = \left[\omega_1, \dots, \omega_n\right] \in \mathbb{R}_{++}^{N}. \end{gathered} \tag{4}$$

The *equal division* (*ED*) *solution* is the solution that distributes the worth $v(N)$ of the *grand coalition* equally among all players, and thus assigns to every (N, v); the payoff is obtained as $ED_i(N, v) = v(N)/n$ for all $i \in N$; it averages the worth of the grand coalition to all players. The player i's *equal surplus division value* $(ES_i(\cdot))$ allocates the surplus evenly after giving every player his individual worth [11].

$$ES_i(N, v) = v(\{i\}) + \left(\frac{1}{n} \times \left(v(N) - \sum_{j \in N} v(j)\right)\right), \text{s.t.}, i \in N. \tag{5}$$

Based on (5), the player i's $WSdV(WS\,dV_i^{\omega}(\cdot))$ is defined by employing the weight ω, which is the positive exogenous given to all players [11].

$$WS\,dV_i^{\omega}(N, v) = v(\{i\}) + \left(\frac{\omega_i}{\sum_{j=1}^{n}(\omega_j)} \times \left(v(N) - \sum_{j \in N} v(j)\right)\right)$$
$$\text{s.t.}, \omega = [\omega_1, \ldots, \omega_n] \in \mathbb{R}_{++}^{N}. \tag{6}$$

Based on the idea of *So*, the *weighted solidarity value* (*WSoV*) is defined by concerning a possibility of relative weight in the coalitional worth. It presents a new distribution rule for marginal contributions. With the weight ω, the player i's $WSoV(WSoV_i^{\omega}(\cdot))$ is the solution given by [12]

$$WSoVi\omega(N, v) = \sum_{S \subseteq N; i \in S} \left(\frac{(n-s)!(s-1)!}{n!} \times \Gamma_i^{\omega}(v, S)\right),$$
$$\Gamma_i^{\omega}(v, S) = \frac{\omega_i}{|\omega(S)|} \times \left(\sum_{i \in S}\left(v(S) - v\left(\frac{S}{i}\right)\right)\right). \tag{7}$$

4.3. The Three-phase Game for the ISMN Routing Algorithm. Routing data in a MANET may need to be transferred over a long distance, before it is received by its final destination. Based on the MANET's characteristics of wireless communications and mobile agents, Ad-hoc On demand Distance Victor (AODV) protocol has been the most widely used routing protocol. In the AODV protocol, possible routing routes are discovered before data are transferred from the source to the destination agents. By providing multiple paths, the reliability of data transmissions can be increased in a MANET environment. In order to keep the entire network connected, mobile agents must provide the local connection information between their neighbor agents over a period of time. For data delivery, agents use control messages when data are transmitted over long distances [18]. To configure multi-hop AODV routing paths, each wireless link is estimated based on its distance and traffic load. The one-hop link cost between agents i and j, that is, $LC_{i,j}$, is obtained as [19]follows:

$$LC_{i,j} = \left((1-\alpha) \times \frac{d_{i,j}}{D_M}\right) + \left(\alpha \times \frac{l_i}{L_M}\right), \tag{8}$$

where D_M and L_M are the maximum coverage range of each agent and the maximum queue length, respectively. The $d_{i,j}$ is the distance from the agent i to the agent j, and l_i is the current queue length of agent i; l_i is defined as the amount of current traffic buffering, which is used as a threshold to detect traffic congestion. The α is a control parameter to estimate the relative current link cost. When the input data rate exceeds the output data rate in the agent i, the routing packets become congested, and $l_i$increases. In this case, a higher value of α is more suitable. By contrast, a lower value of α is more suitable. In the proposed scheme, the α value is dynamically adjusted based on the current buffer space ratio where $\alpha = l_i/L_M$.

Based on the AODV protocol, multiple multi-hop routing paths in the MANET are constructed, and the q least cost paths are selected for our multipath routing algorithm, which adaptively distributes routing packets through these paths. To provide a fair and efficient solution to the packet distribution problem, we adopt the concept of coalitional game, and the established paths are assumed as game players. Therefore, a coalition is formed by the combination of selected routing paths, and our coalitional game is a q-person game. Path $1 \le h \le q$ from the source agent s to the destination agent e has the set $(\mathbb{S}_h^{s,e})$ of all one-hop links, and the path h's utility function $(U_h(s,e))$ is defined as follows:

$$U_h(s,e) = \frac{\psi}{\sum_{g \in \mathbb{S}_h^{s,e}} C(g)}, \tag{9}$$

where ψ is a control factor and $C(g)$ is the cost function for the link g, which is defined using (8). Generally, the packet distribution problem for q routing paths leads to a conflict situation similar to the bankruptcy problem for q creditors. The bankruptcy problem assumes that a company becomes bankrupt and owes money to q creditors; this money must be divided among these creditors. The bankruptcy problem is a pair $(E, \mathbf{c})$; E represents the company's remaining money and $\mathbf{c} = (c_1, \ldots, c_q)$ is the vector of creditors' claims where $0 < E < \sum_{i=1}^{q} c_i$. The utility function $v(S)^{E,c}$ for the coalition S is defined based on the bankruptcy model [19]:

$$v(S)^{E,c} = \max\left\{0;\ E - \sum_{i \in S} c_i\right\}. \tag{10}$$

In the $\mathbb{G}_{RT}^{F}$, we distribute the $\mathfrak{M}_{RT}$ for the $\mathscr{W}$ and $\mathscr{Z}$. Simply, we consider that one satellite is already deployed at the desired locations to ensure maritime network demands. Therefore, we have two ways to connect from the source to the destination agents: one is established in the MANET ($\mathscr{Z}$), and the other is connected by using the satellite network ($\mathscr{W}$). The utility functions of $\mathscr{W}$ and $\mathscr{Z}$ from the source agent s to the destination agent e, that is, $\mathscr{U}_{\mathscr{W}}^{RT}(s,e)$ and $\mathscr{U}_{\mathscr{Z}}^{RT}(s,e)$, are defined as follows:

$$\begin{cases} \mathscr{U}_{\mathscr{W}}^{RT}\left((s,e), \mathfrak{M}_{RT}^{\mathscr{W}}\right) = \left(\left(A_{\mathscr{W}} \times \dfrac{\left(\chi + f^{RT}\right)}{\mathscr{C}_{\mathscr{W}}}\right) \times \mathfrak{M}_{RT}^{\mathscr{W}}\right), \\ \mathscr{U}_{\mathscr{Z}}^{RT}\left((s,e), \mathfrak{M}_{RT}^{\mathscr{Z}}\right) = \left(\sum_{P_k^{(s,e)} \in \mathbb{P}} \mathbf{min}_{g} \left\{\mathscr{A}_{\mathscr{Z}}(g) \,\middle|\, g \in \mathbb{S}_{P_k}^{s,e}\right\}\right) \times \dfrac{\mathfrak{M}_{RT}^{\mathscr{Z}}}{\mathscr{C}_{\mathscr{Z}}}, \end{cases} \tag{11}$$

where $A_{\mathscr{W}}$ is the currently available link capacity of $\mathscr{W}$ and f^{RT} is the current failure ratio of the RT data services. χ is a control parameter for $\mathscr{U}^{RT}(s,e)$, and $\mathscr{A}_{\mathscr{Z}}(g)$ is the currently available capacity of the one-hope link g. Therefore, $\mathscr{U}^{RT}_{\mathscr{Z}}(\cdot)$ is significantly affected by the sum of the bottleneck links of each path. $\mathscr{C}_{\mathscr{W}}$ and $\mathscr{C}_{\mathscr{Z}}$ are the cost factors of the $\mathscr{W}$ and $\mathscr{Z}$, respectively. Based on the $\mathscr{U}^{RT}_{\mathscr{W}}(\cdot)$ and $\mathscr{U}^{RT}_{\mathscr{Z}}(\cdot)$, we can get the $v(S)$ with (E,c). Especially, the $\mathbb{G}^{F}_{RT}$ is a two-player game with the $\mathscr{W}$ and $\mathscr{Z}$where $v(\{\mathscr{W}\}) = c_{\mathscr{W}} = \mathscr{U}^{RT}_{\mathscr{W}}((s,e),\mathfrak{M}^{\mathscr{W}}_{RT})$ with $\mathfrak{M}^{\mathscr{W}}_{RT} = \mathfrak{M}_{RT}$, and $v(\{\mathscr{Z}\}) = c_{\mathscr{Z}} = \mathscr{U}^{RT}_{\mathscr{Z}}((s,e),\mathfrak{M}^{\mathscr{Z}}_{RT})$ with $\mathfrak{M}^{\mathscr{Z}}_{RT} = \mathfrak{M}_{RT}$, and $E = \vartheta \times (c_{\mathscr{W}} + c_{\mathscr{Z}})$; ϑ is an adjustment factor to estimate the grand coalition value. In the proposed scheme, we adopt the *WSdV* as the solution of $\mathbb{G}^{F}_{RT}$; it is given by

$$WS\,dV^{\omega}_{\mathscr{P}_i \in \mathbb{N}}(\mathbb{N},v) = v(\{\mathscr{P}_i\}) + \left(\omega_{\mathscr{P}_i} \times \left(v(\mathbb{N}) - \sum_{\substack{\mathscr{P}_j \in \mathbb{N};\\ \mathscr{P}_i \neq \mathscr{P}_j}} v(\mathscr{P}_j)\right)\right)$$
$$\mathscr{P}_i \in \mathbb{N} = \{\mathscr{W},\mathscr{Z}\},\ \omega_{\mathscr{W}} = \mathbf{max}\left(\mu, f^{RT}\right),\ \omega_{\mathscr{Z}} = 1 - \omega_{\mathscr{W}}, \tag{12}$$

where μ is an adjustment parameter for determining $\omega_{\mathscr{W}}$ value. According to (12), the $\mathscr{W}$ and $\mathscr{Z}$ obtain their *WSdVs* such as $WS\,dV^{\omega}_{\mathscr{W}}(\mathbb{N},v)$ and $WS\,dV^{\omega}_{\mathscr{Z}}(\mathbb{N},v)$. Finally, the $\mathfrak{M}_{RT}$ is divided into $\mathfrak{M}^{\mathscr{W}}_{RT}$ and $\mathfrak{M}^{\mathscr{Z}}_{RT}$ as follows:

$$\begin{cases} \mathfrak{M}^{\mathscr{W}}_{RT} = \dfrac{WS\,dV^{\omega}_{\mathscr{W}}(\mathbb{N},v)}{WS\,dV^{\omega}_{\mathscr{W}}(\mathbb{N},v) + WS\,dV^{\omega}_{\mathscr{Z}}(\mathbb{N},v)} \times \mathfrak{M}_{RT}, \\ \\ \mathfrak{M}^{\mathscr{Z}}_{RT} = \left(\mathfrak{M}_{RT} - \mathfrak{M}^{\mathscr{W}}_{RT}\right) = \dfrac{WS\,dV^{\omega}_{\mathscr{Z}}(\mathbb{N},v)}{WS\,dV^{\omega}_{\mathscr{W}}(\mathbb{N},v) + WS\,dV^{\omega}_{\mathscr{Z}}(\mathbb{N},v)} \times \mathfrak{M}_{RT}. \end{cases} \tag{13}$$

In the $\mathbb{G}^{S}_{RT}$, we distribute the $\mathfrak{M}^{\mathscr{Z}}_{RT}$ for multiple paths, that is, $P_{1\le k\le q}$, in the $\mathbb{P}$. The $P_k \in \mathbb{P}$ is a game player and his utility function from the source agent s to the destination agent e, that is, $\mathbb{U}^{RT}_{P_k}(s,e)$, is defined as follows:

$$\mathbb{U}^{RT}_{P_k}\left((s,e),\mathfrak{M}^{\mathscr{Z},P_k}_{RT}\right) = U_{P_k}(s,e) \times \frac{\mathfrak{M}^{\mathscr{Z},P_k}_{RT}}{\log\left(\delta + \mathbb{H}\left(P^{(s,e)}_k\right)\right)}, \tag{14}$$

where $\mathfrak{M}^{\mathscr{Z},P_k}_{RT}$ is the allocated RT data packet amount for the P_k. δ is an adjustment parameter for $\mathbb{U}^{RT}_{P_k}(\cdot)$ and $\mathbb{H}(P^{(s,e)}_k)$ is the link hop number of P_k. In particular, the $\mathbb{G}^{S}_{RT}$ is a q-player game with $P_{1\le k\le q}$ where $v(P^{(s,e)}_k) = c_{P_k} = \mathbb{U}^{RT}_{P_k}((s,e),\mathfrak{M}^{\mathscr{Z},P_k}_{RT})$ with $\mathfrak{M}^{\mathscr{Z},P_k}_{RT} = \mathfrak{M}^{\mathscr{Z}}_{RT}$, and $E = \vartheta \times (\sum_{1\le k\le q} v(P^{(s,e)}_k))$. In the $\mathbb{G}^{S}_{RT}$, we adopt the *WSV* as the solution concept; it is given by

$$WSV^{\omega}_{P_k}(\mathbb{P},v) = \sum_{S\subseteq\mathbb{P};P_k\in S}\left(\frac{\omega_{P_k}}{\sum_{P_l\in S}\left(\omega_{P_l}\right)} \times d_v(s)\right) \text{s.t.}, P_k \in \mathbb{P}, \omega = \left[\omega_{P_1},\ldots,\omega_{P_q}\right] \in \mathbb{R}^{q}_{++} \text{ and } \omega_{P_k} = \frac{\mathfrak{P}^{\omega} - \mathbb{H}\left(P^{(s,e)}_k\right)}{\sum_{P_l\in\mathbb{P}}\left(\mathfrak{P}^{\omega} - \mathbb{H}\left(P^{(s,e)}_l\right)\right)}, \tag{15}$$

where $\mathfrak{P}^{\omega}$ is the modification factor for the weight calculation. According to (15), the P_k obtains its *WSV*, such as $WSV^{\omega}_{P_k}(\mathbb{P},v)$, and the $\mathfrak{M}^{\mathscr{Z}}_{RT}$ is divided for the P_k, that is, $\mathfrak{M}^{\mathscr{Z},P_k}_{RT}$, as follows:

$$\mathfrak{M}^{\mathscr{Z},P_k}_{RT} = \frac{WSV^{\omega}_{P_k}(\mathbb{P},v)}{\sum_{P_l\in\mathbb{P}} WSV^{\omega}_{P_l}(\mathbb{P},v)} \times \mathfrak{M}^{\mathscr{Z}}_{RT}. \tag{16}$$

In the $\mathbb{G}^{T}_{NRT}$, we distribute the $\mathfrak{M}^{\mathscr{Z}}_{NRT}$ for the multiple paths in the $\mathbb{P}$. Similar to the $\mathbb{G}^{S}_{RT}$, the P_k is a game player and his utility function, that is, $\mathfrak{U}^{NRT}_{P_k}(s,e)$ is defined as follows:

$$\mathfrak{U}^{NRT}_{P_k}\left((s,e),\mathfrak{M}^{\mathscr{Z},P_k}_{NRT}\right) = U_{P_k}(s,e) \times \left(1 - \left(\varepsilon \times \frac{l^{M}_{P_k}}{L_M}\right)\right) \times \mathfrak{M}^{\mathscr{Z},P_k}_{NRT}, \tag{17}$$

where $\mathfrak{M}^{\mathscr{Z},P_k}_{NRT}$ is the allocated NRT data packet amount for the P_k. ε is a control factor for $\mathfrak{U}^{NRT}_{P}(\cdot)$ and $l^{M}_{P_k}$ is the queue length of the most congested link in the P_k. The $\mathbb{G}^{T}_{NRT}$ is also a q-player game with P_k where $v(P^{(s,e)}_k) = c_{P_k} = \mathfrak{U}^{NRT}_{P_k}((s,e),\mathfrak{M}^{\mathscr{Z},P_k}_{NRT})$ with $\mathfrak{M}^{\mathscr{Z},P_k}_{NRT} = \mathfrak{M}^{\mathscr{Z}}_{NRT}$, and $E = \vartheta \times (\sum_{1\le k\le q} v(P^{(s,e)}_k))$. In the $\mathbb{G}^{T}_{NRT}$, we adopted the *WSoV* as the solution concept; it is given by

Table 2: System parameters used in the simulation experiments.

Parameter	Value	Description	
n	70	The total number of ships	
m	30	The total number of floating buoys	
k	10	The number of IoT devices in each ship	
q	4	The number of selected routing paths	
D_M	1,500 km	The maximum coverage range	
L_M	1 Gbits	The maximum queue length	
ψ	1	a control factor for the $U(\cdot)$	
χ	0.5	a control parameter for $\mathscr{U}^{RT}(\cdot)$	
$\mathscr{C}_{\mathscr{W}}, \mathscr{C}_{\mathscr{Z}}$	10, 1	Cost factors for the $\mathscr{W}$ and $\mathscr{Z}$, respectively,	
$\mathbb{C}^{\mathscr{W}}$	50 gbps	Communication capacity of satellite	
ϑ	0.8	An adjustment factor for the grand coalition value	
μ	0.5	An adjustment parameter for $\omega_{\mathscr{W}}$	
δ	3	An adjustment parameter for $\mathbb{U}_P^{RT}(\cdot)$	
ε	0.2	An control factor for $\mathfrak{U}_P^{NRT}(\cdot)$	
$\mathfrak{P}^{\omega}$	25	a modification factor for the weight calculation	
Applications	**Service duration**	**Communication requirement**	**Preference level**
1	20 t	256 kbps	RT type
2	25 t	192 kbps	RT type
3	30 t	256 kbps	RT type
4	35 t	320 kbps	NRT type
5	40 t	512 kbps	NRT type
6	15 t	640 kbps	NRT type

$$WSoV_{P_k}^{\omega}(\mathbb{P}, v) = \sum_{S \subseteq \mathbb{P}; P_k \in S} \left(\frac{(q - |S|)!\,(|S| - 1)!}{q!} \times \Gamma_{P_k}^{\omega}(v, S) \right)$$

$$\text{s.t.}, \begin{cases} P_k \in \mathbb{P}, \omega \in \mathbb{R}_{++}^{q}, \\ \omega_k = \dfrac{L_M - l_{P_k}^M}{\sum_{P_l \in \mathbb{P}} \left(L_M - l_{P_l}^M \right)}, \\ \Gamma_{P_k}^{\omega}(v, S) = \dfrac{\omega_k}{|\omega(S)|} \times \left(\sum_{P_l \in S} \left(v(S) - v\left(\dfrac{S}{P_l} \right) \right) \right). \end{cases} \tag{18}$$

According to (18), the P_k obtains its $WSoV$ similar to $WSoV_{P_k}^{\omega}(\mathbb{P}, v)$, and the $\mathfrak{M}_{NRT}^{\mathscr{Z}}$ is divided for the P_k, that is, $\mathfrak{M}_{NRT}^{\mathscr{Z},P_k}$, as follows:

$$\mathfrak{M}_{NRT}^{\mathscr{Z},P_k} = \frac{WSoV_{P_k}^{\omega}(\mathbb{P}, v)}{\sum_{P_l \in \mathbb{P}} WSoV_{P_l}^{\omega}(\mathbb{P}, v)} \times \mathfrak{M}_{NRT}^{\mathscr{Z}}. \tag{19}$$

4.4. Main Steps of Our Proposed ISMN Routing Algorithm.

In this study, we developed a novel three-phase coalitional game model for adaptively distributing routing packets in an ISMN system. In the first and second phase games, RT data services are operated in the satellite and maritime networks while adopting the concepts of *WSdV* and *WSV*. In the third phase game, NRT data services are manipulated in the MANET according to the idea of *WSoV*. Based on the real-time online monitoring, they work together to achieve an appropriate system performance while ensuring good global properties. Owing to the desirable characteristics of value solutions, we can maximize the system throughput while achieving service preference and fairness among wireless communication links. The main steps of our proposed algorithm are described by the following Flowchart:

Step 1: To implement the proposed packet distribution algorithm, the values of the adjustment parameters and control factors are listed in Table 2, and the simulation setup is presented in Section IV.

Step 2: At each time epoch, multiple IoT devices in each ship independently generate their RT and NRT routing data, and request routing operations on the ISMN platform.

Step 3: In MANET, each individual wireless link is estimated using (8), and multiple paths from the source to destination agents are established according to the AODV protocol. The utility function of each path is defined based on (9).

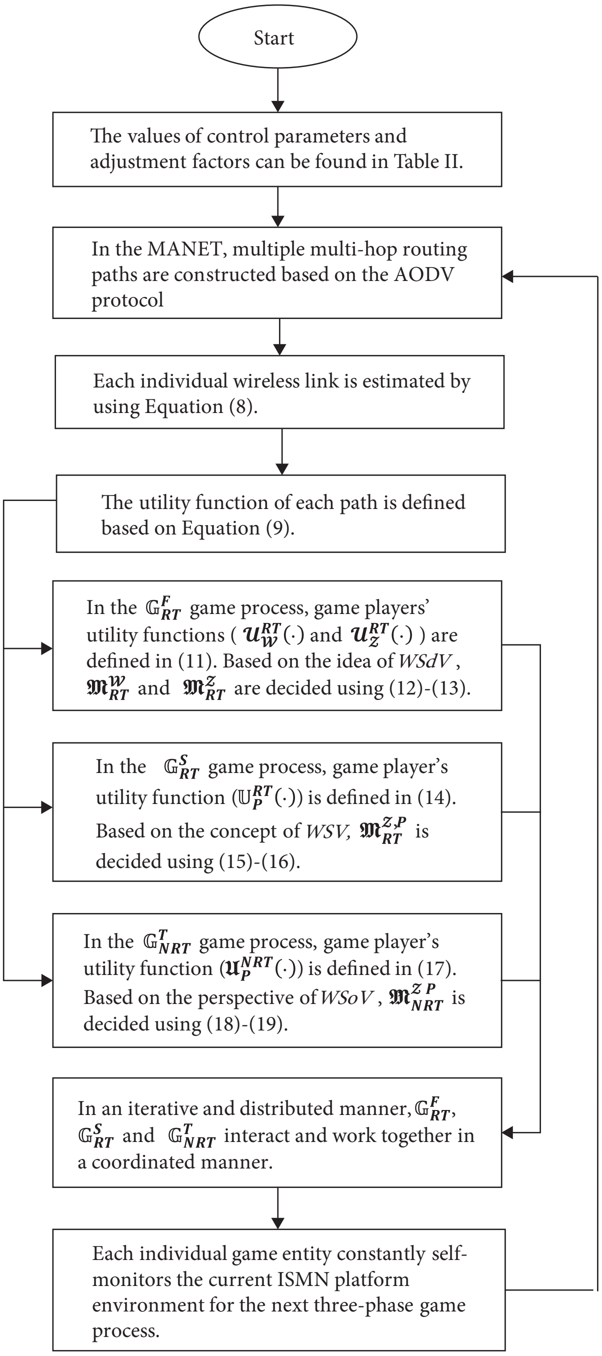
Step 4: In the $\mathbb{G}_{RT}^{F}$ game process, $\mathscr{W}$ and $\mathscr{Z}$ are game players, and their utility functions, that is, $\mathscr{U}_{\mathscr{W}}^{RT}(\cdot)$ and $\mathscr{U}_{\mathscr{Z}}^{RT}(\cdot)$ are defined in (11). Based on the idea of *WSdV*, $\mathfrak{M}_{RT}$ is divided into the $\mathscr{W}$ and $\mathscr{Z}$, that is, $\mathfrak{M}_{RT}^{\mathscr{W}}$ and $\mathfrak{M}_{RT}^{\mathscr{Z}}$ using (12)-(13).

Step 5: In the $\mathbb{G}_{RT}^{S}$ game process, multiple paths in the $\mathbb{P}$ are game players, and their utility functions, that is, $\mathbb{U}_P^{RT}(\cdot)$, are defined in (14). Based on the concept of *WSV*, $\mathfrak{M}_{RT}^{\mathscr{Z}}$ is divided for each game player $P_{1 \le k \le q}$, that is, $\mathfrak{M}_{RT}^{\mathscr{Z},P_k}$, using (15) and (16).

Step 6: In the $\mathbb{G}_{NRT}^{T}$ game process, multiple paths in the $\mathbb{P}$ are game players, such as the $\mathbb{G}_{RT}^{S}$ game, and their utility functions, that is, $\mathfrak{U}_P^{NRT}(\cdot)$, are defined in (17). Based on the perspective of *WSoV*, $\mathfrak{M}_{NRT}^{\mathscr{Z}}$ is divided for the P_k, that is, $\mathfrak{M}_{NRT}^{\mathscr{Z},P_k}$, by using (18) and (19).

Step 7: In an iterative and distributed manner, $\mathbb{G}_{RT}^{F}$, $\mathbb{G}_{RT}^{S}$, and $\mathbb{G}_{NRT}^{T}$ interact and work together in a coordinated manner.

Step 8: Each individual game entity constantly self-monitors the current ISMN platform environment, and proceeds to Step 2 for the next three-phase coalitional game process.



5. Performance Evaluation

In this section, we evaluate the performance of the proposed scheme using a simulation. First, we constructed a simulation environment using MATLAB to validate the contributions of this paper [20]. Second, the performance of our proposed scheme is compared with the existing *INPM*, *SMUC,* and *MRCA* protocols in [2, 14, 15]. For the performance comparison, we adopted the following simulation scenario and environment setup.

(i) The simulated ISMN platform consists of 70 ships and 30 buoys where $|\mathcal{S}|$ =70 and $|\mathfrak{B}|$ =30. They are evenly distributed in a 10,000 × 10,000 Km square sea area. Each ship and buoy can directly contact neighboring agents.

(ii) Four TBSs are located on each side of the sea area, and the source and destination agents are randomly selected.

(iii) The satellite communication capacity ($\mathbb{C}^{\mathcal{W}}$) is 50 Gbps.

(iv) For each ship, there are 10 MUDs where $|\mathbb{D}^{\mathcal{S}}|$ =10, and they generate routing data, which are categorized into RT and NRT services. At each time epoch, the generation process for data is Poisson with rate Λ (services/t), and the range of offered services was varied from 0 to 3.0.

(v) Each link capacity of the MANET is assumed to be 3 Gbps. The D_M and L_M values are 1,500 km and 1 GB, respectively.

(vi) We assumed that the network topology remains static during the performance observation period.

(vii) Six different types of application data were assumed based on their communication requirements, preference level, and service duration times.

(viii) System performance measures obtained on the base of 100 simulation runs are plotted as a function of the offered data request load.

In Figure 2, the throughput results of our proposed scheme and the *INPM*, *SMUC,* and *MRCA* protocols in [2, 14, 15] are plotted based on the different service workload rates. This is an important performance criterion for the system operators. In general, the total throughput of all the schemes increases when the service rate increases, which is intuitive. However, it is observed that the throughput of our proposed scheme is higher than that of the other existing schemes from low to heavy workload intensities. The main reason for this is that we effectively make packet distribution decisions based on a step-by-step interactive approach. The simulation results confirmed the performance gain of our three-phase coalitional game approach.

Figure 3 compares the failure ratios of the RT data services for all schemes. As shown in the resulting curves, the failure ratio increases with an increase in workload in the ISMN system. This is because as the routing workload increases, the average routing capacity decreases. Thus, the requests for RT data services are likely to be rejected, and the failure ratio increases. All schemes have similar trends; however, our scheme performs significantly better than other protocols. This reason is because with an increase in the workload rate, the limited ISMN routing capacity in our

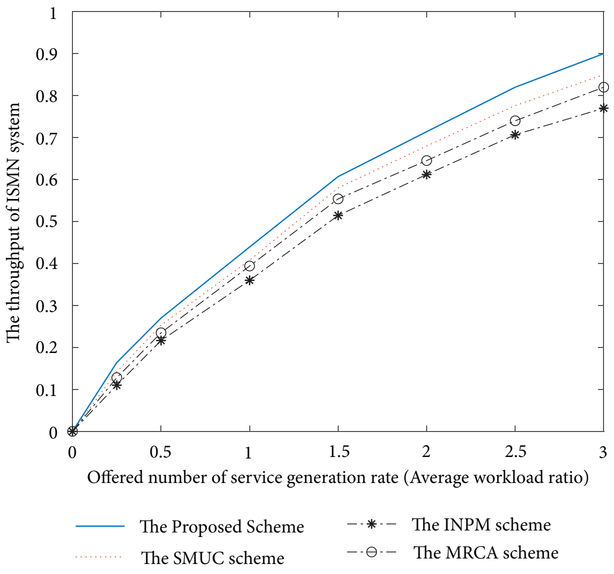


Figure 2: The throughput of ISMN system.

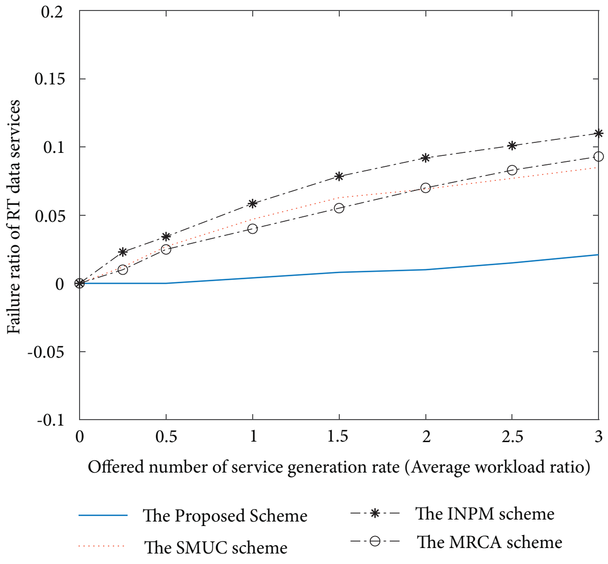


Figure 3: Failure ratios of RT data services.

proposed scheme is optimally shared while giving the preference to RT data services; it means that our scheme can lower the failure ratio of RT data services than other existing protocols.

Fairness comparisons among one-hop links in the ISMN platform are plotted in Figure 4. From the viewpoint of an individual network agent, it is another important performance criterion. Paths in MANET consist of individual one-hop connections between neighboring agents, and routing data are transferred using these paths. To avoid traffic congestion, workload fairness among the links is desirable. Traditionally, the main challenge of coalitional value solutions is to ensure a relevant tradeoff between efficiency and fairness; the major characteristic of *WSdV*, *WSV*, and *WSoV* solutions is to provide a fair-efficient solution for the resource sharing problem. This feature is directly implied in the packet distribution problem of the ISMN system. Therefore, our value solution-based approach can achieve the best link workload fairness compared to the *INPM*, *SMUC*, and *MRCA* schemes.

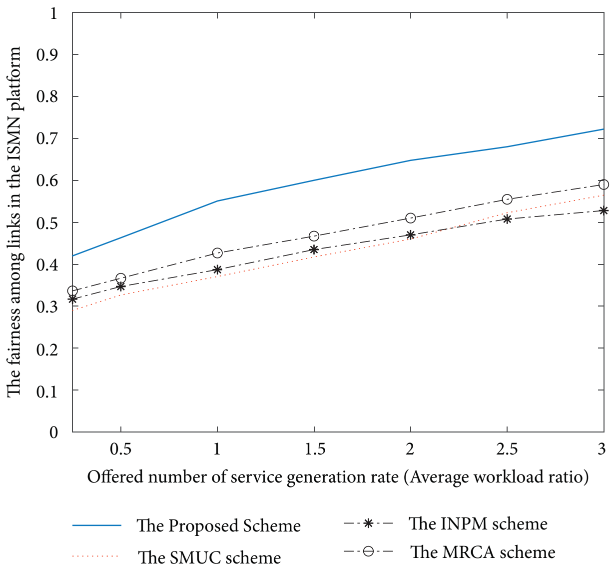


Figure 4: The workload fairness among wireless links.

6. Summary and Conclusions

The recent emergence of 6G communication technologies in maritime networks has led to the introduction of ISMN infrastructure. In this study, we provide a new ISMN routing scheme, which can solve the packet distribution problem for multiple AODV paths. Novel solution ideas of *WSV*, *WSoV*, and *WSdV* have been investigated to optimally distribute RT and NRT data packets. Based on the characteristics of data type and service preferences, we developed a new three-phase coalitional game model to achieve greater and reciprocal advantages. The games in each phase interact with each other in a distributed online fashion, and work together to reach a mutually desirable solution. Under dynamically changing ISMN environments, our approach can leverage reciprocal consensus from complicated routing control issues. The experimental results prove that the proposed scheme improves the system throughput and fairness of link usage on the ISMN platform. Furthermore, we can ensure the preference of RT data services for mission-critical applications compared with the existing *INPM*, *SMUC*, and *MRCA* protocols.

In the future, we plan to conduct real-world experiments to validate and optimize the proposed ISMN multipath routing algorithm. In addition, dynamic agent positions will be considered in the routing algorithm to address more complex and realistic scenarios. Besides, an online learning process for the model parameters can be designed to adapt to changing ISMN situations. Additionally, we plan to extend this work by incorporating the fuzzy characteristics of service satisfaction with necessary modifications in the coalitional game procedure.

Data Availability

The data used to support the findings of this study are available from the author upon request (swkim01@sogang.ac.kr). mailto:swkim01@sogang.ac.kr.

Conflicts of Interest

The author declares that there are no conflicts of interests regarding the publication of this paper.

Authors' Contributions

The author is a sole author of this work and ES (i.e., participated in the design of the study and performed the statistical analysis).

Acknowledgments

This research was supported by the MSIT (Ministry of Science and ICT), Korea, under the ITRC (Information Technology Research Center) support program (IITP-2022-2018-0-01799) supervised by the IITP (Institute for Information & communications Technology Planning & Evaluation), and was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education (No. 2021R1F1A1045472).

References

[1] X. You, C. X. Wang, J. Huang et al., "Towards 6G wireless communication networks: vision, enabling technologies, and new paradigm shifts," *Science China Information Sciences*, vol. 64, no. 1, pp. 110301–110374, 2021.

[2] S. H. Sheikh, M. Umer, and C. S. Hong, "Reliable integrated space-oceanic network profit maximization by bender decomposition approach," in *Proceedings of the IEEE International Conference on Information Networking (ICOIN)*, pp. 1–6, South Korea, January 2021.

[3] S. Peng, Y. Wang, H. Xiao, and B. Lin, "Implementation of an improved AODV routing protocol for maritime ad-hoc networks," in *Proceedings of the IEEE International Congress on Image and Signal Processing, BioMedical Engineering and Informatics (CISP-BMEI)*, pp. 1–5, China, October 2020.

[4] K. L. A. Yau, A. R. Syed, W. Hashim, J. Qadir, C. Wu, and N. Hassan, "Maritime networking: bringing internet to the sea," *IEEE Access*, vol. 7, pp. 48236–48255, 2019.

[5] X. Li, W. Feng, Y. Chen, C. X. Wang, and N. Ge, "Maritime coverage enhancement using UAVs coordinated with hybrid satellite-terrestrial networks," *IEEE Transactions on Communications*, vol. 68, no. 4, pp. 2355–2369, 2020.

[6] S. Aslam, M. P. Michaelides, and H. Herodotou, "Internet of ships: a survey on architectures, emerging applications, and challenges," *IEEE Internet of Things Journal*, vol. 7, no. 10, pp. 9714–9727, 2020.

[7] C. K. Deepak and D. K. Uttam, "Performance analysis of real and non real time traffic over WLAN using connection admission control policy," in *Proceedings of the IEEE Second UKSIM European Symposium on Computer Modeling and Simulation*, pp. 1–7, Liverpool, U.K, September 2008.

[8] S. Kim and P. K. Varshney, "An integrated adaptive bandwidth management framework for QoS-sensitive multimedia cellular networks," *IEEE Transactions on Vehicular Technology*, vol. 53, no. 3, pp. 835–846, 2004.

[9] S. Kim, *Game Theory Applications in Network Design*, IGI Global, Hershey, PA, U.S.A, 2014.

[10] B. Serge, "Nlénd oum and lawrence diffo lambo, "the solidarity value as a probabilistic solidarity value," *Theoretical Economics Letters*, vol. 10, no. 6, pp. 1397–1425, 2020.

[11] H. Yang, W. Wang, and Z. Ding, "The weighted surplus division value for cooperative games," *Symmetry*, vol. 11, no. 9, pp. 1–10, 2019.

[12] E. Calvo and E. L. Gutiérrez, "Axiomatic characterizations of the weighted solidarity values," *Mathematical Social Sciences*, vol. 71, pp. 6–11, 2014.

[13] V. R. Kavitha and M. Moorthi, "A quality of service load balanced connected dominating set–stochastic diffusion search (CDS–SDS) network backbone for MANET," *Computer Networks*, vol. 151, pp. 124–131, 2019.

[14] Y. Wang, W. Feng, J. Wang, and T. Q. S. Quek, "Hybrid satellite-UAV-terrestrial networks for 6G ubiquitous coverage: a maritime communications perspective," *IEEE Journal on Selected Areas in Communications*, vol. 39, no. 11, pp. 3475–3490, 2021.

[15] J. Xing, Q. Li, H. Sun, J. Qi, Z. Zhu, and J. Wang, "Multi-radio multi-channel assignment algorithm in maritime wireless mesh networks," *IEEE Access*, vol. 7, pp. 85903–85912, 2019.

[16] A. Casajus, "Relaxations of symmetry and the weighted Shapley values," *Economics Letters*, vol. 176, pp. 75–78, 2019.

[17] G. Haeringer, "A new weight scheme for the Shapley value," *Mathematical Social Sciences*, vol. 52, no. 1, pp. 88–98, 2006.

[18] M. Atto, R. J. Mstafa, and A. Alkhayyat, "Improving AODV routing protocol for image transmission over mobile video sensor networks," *IEEE Access*, vol. 8, pp. 169396–169407, 2020.

[19] S. Kim, "Cooperative game theoretic online routing scheme for wireless network managements," *IET Communications*, vol. 4, no. 17, pp. 2074–2083, 2010.

[20] S. Kim, "Cooperative federated learning-based task offloading scheme for tactical edge networks," *IEEE Access*, vol. 9, pp. 145739–145747, 2021.