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6G and routing mechanism in a space-air-ground integrated network: DPAC

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***Abstract*—Large advancements in imaging, presence technology and location awareness are anticipated to be made possible by the 6G technology market. The 6G computational infrastructure, in conjunction with artificial intelligence (AI), will be able to decide where computing should take place, including decisions regarding data storage, processing, routing algorithms, and sharing. The Space-Air-Ground Integrated Network (SAGIN), which combines satellite networks, air network platforms, and ground-based networks, has been affected by more and more academics in academia and industry in recent years due to the breakthroughs in high-throughput satellite technology and small satellite constellation technology. SAGIN may combine network advantages at many levels and play a significant role in a number of industries, including military operations, ground monitoring, mapping, navigation, and guidance. Routing optimization is essential for directing data packets between network nodes along the optimum end-to-end routes depending on particular network conditions (from the source to the destination) regardless of the type of network, a poor routing strategy can negatively impact the network's overall performance. Since high network congestion is expected to be a major problem with 6G-SAGIN, the routing algorithm will be a major problem. In this paper, Several routing approaches are covered, and a simulation of the Dynamic priority ant colony routing algorithm(DPAC) is attached in the simulation part.**

I. Space–Air–Ground Integrated Network

A. Overview of SAGIN

Ground networks, satellite systems, and air networks are all included in space-air-ground integrated networks (SAGIN), which increase data transmission dependability and throughput[1]. A SAGIN's several interconnected networks enable wider coverage than a conventional ground network[2]. It can offer a secure information infrastructure for user activities based on land, sea, air, and space[3]. A SAGIN also increases the functionality of wireless networks, which makes it crucial for many cutting-edge applications like autopilot and earth monitoring[4]. Future communication will involve a variety of intricate jobs and situations. Ground communication infrastructure may be harmed during natural disasters and other widespread situations, making it difficult to meet communication demands. Fast networking and flexible deployment are made possible by SAGINs. In addition, SAGINs, which are a novel development in future communication networks, will play a bigger part in the 6G era.

B. Introduction of SAGIN Architecture

Future SAGINs will be able to operate in sophisticated conditions, making them a growth trend in communication networks. The architecture of a space-air-ground integrated network is depicted in Figure 1. It comprises of a space network, an air network, and a ground network.

By integrating several networks to construct a complex topology, this network is able to actualize the sharing of global information and resources[5]. The following are the specific details of each network:

Space Network: Space Network A variety of communication satellites are dispersed throughout the space network in varied orbits [6]. Altitude and channel width are two characteristics that can be used to categorize satellite networks. Satellites that orbit at different altitudes fall into the geostationary orbit (GEO), middle-earth orbit (MEO), and low-earth orbit (LEO) categories. Broadband and narrowband are two different channel width types. The space layer's principal

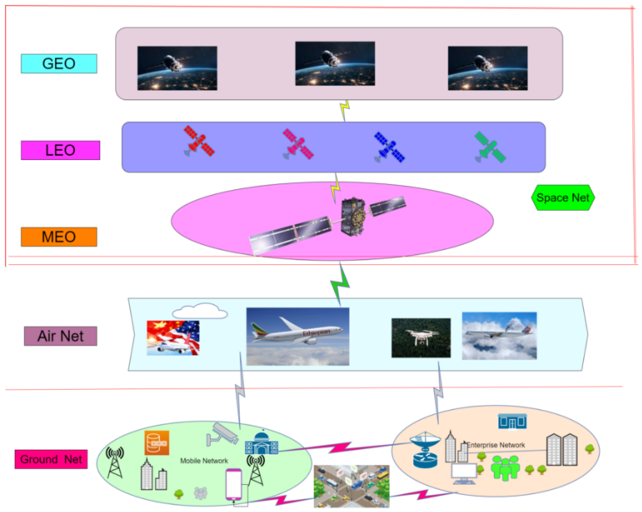

Fig. 1: SAGIN Architecture

benefit is that it offers a routing bypass feature when direct connectivity between the space layer and the ground layer is compromised. SAGINs can be used thanks to this bypass capability.

Air Network: A wide range of aerial communication tools, including balloons and unmanned aerial vehicles, make up the air network. Three qualities define the aerial layer: low resource cost, simple deployment, and broad coverage[7]. These features enable the aerial layer to perform routing duties for the ground layer and regional wireless access services, making it more advantageous than a base station on the ground.

Users and various ground communication networks, such as cellular and wireless local area networks, make up the ground network. Although the ground layer offers fast data speeds, certain rural places are not covered.

Ground Network: Each network tier has advantages and disadvantages. There is a significant transmission delay despite the satellite network's ability to provide worldwide coverage of the planet. The ground network is an addition to the satellite network because of its short propagation latency. However, unforeseen events and human activity can quickly affect the ground network. SAGINs feature an aerial layer in comparison to conventional terrestrial networks, which gives them greater coverage, greater openness, and greater resistance to damage of all kinds.

C. *Comparison of Different Networks:*

Each network tier has advantages and disadvantages. There is a significant transmission delay despite the satellite network's ability to provide worldwide coverage of the planet. The ground network is an addition to the satellite network because of its short propagation latency. However, unforeseen events and human activity can quickly affect the ground network. SAGINs feature an aerial layer in comparison to conventional terrestrial networks, which gives them greater coverage, greater openness, and greater resistance to damage of all kinds.

D. *Advantages of SAGIN Architecture :*

The three network layers in the SAGIN architecture can cooperate and depend on one another. To create a multilayer broadband wireless network, it connects heterogeneous networks. The cost of sixth generation (6G) ground networks might be greatly reduced if the satellites could effectively reach remote and rural areas. While doing so, it offers benefits in terms of coverage, throughput, dependability, and flexibility, opening up a wide range of application possibilities in next-generation networks. Additionally, SAGINs are crucial in numerous circumstances, including navigation, remote sensing, and communication.

II. Main Issues in Routing

A kind of adaptive routing is employed by the majority of large packet networks, in which the paths between origins and destinations utilized to route new traffic occasionally alter in response to congestion. The rationale behind this is that changes in the statistics of the input traffic load can cause congestion to develop in specific areas of the network. The routing algorithm should then attempt to modify its paths in order to divert traffic away from the congested area. A routing algorithm's two major tasks include choosing the best routes for different origin-destination pairings and delivering messages to the right places once the routes have been chosen.The second function makes use of a variety of protocols and data structures and is theoretically simple. The first task (route selection) and how it impacts network performance will be the main points of discussion.

The routing method has a significant impact on two key performance metrics: throughput (quality of service) and average packet delay (quality of service).

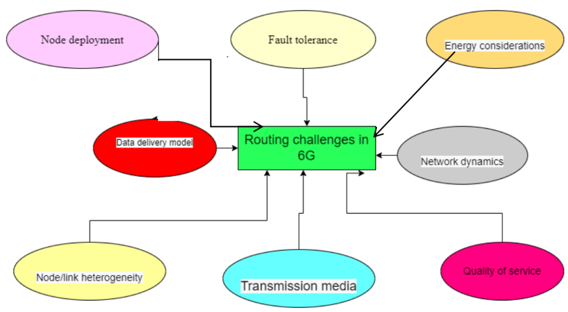

Fig. 2: Routing Challenges in 6G-SAGIN

Since they are highly dynamic network environments, most existing space–air–ground integrated network routing strategies are insufficient for interactive information transmission between heterogeneous layers. In particular, satellite networks are characterized by high dynamics. The satellite networks are constructed by integrating several satellite networks and hierarchical structures. The satellite networks can be divided into single and multi-layer satellite networks. The single-layer satellite network consists of one or more orbital planes. Each satellite is generally equipped with an inter-satellite link to communicate with neighboring satellites. Meanwhile, the satellite can interact with the ground gateway station and the user station via the feeder and user links, creating a complex communication system with multiple links

III. Routing Algorithm

The complex architecture, changeable constellation topology, and frequent inter-satellite connection switching problems bring great challenges to the routing designs of satellite networks, making the study of the routing methods in space,air, and ground networks a research hotspot. Currently, existing routing schemes are generally aimed at single-layer network routing, and cooperative routing between multiple layers has not made much progress. Due to the diversity of node types in the network, the limitations of different layers are also different. For example, satellite bandwidth resources are limited, time delay is large, hot air balloon energy is limited, and the ground is easily affected by the geographical environment.

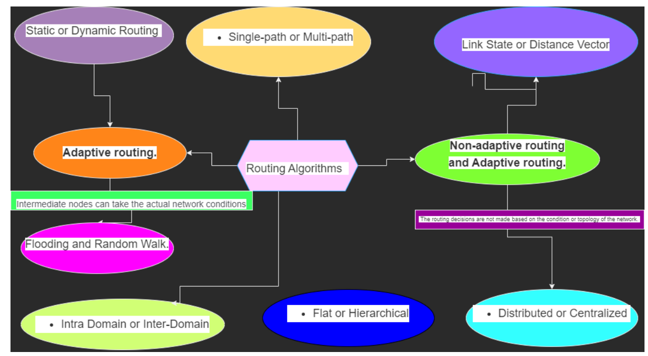

Fig. 3: Routing Algorithms.

Dynamic routing algorithms : Low-cost, high-precision long-distance communication via low-orbit satellites is a recent development. To ensure that this technology can be used, efficient data transfer between the satellite and the ground stations is a requirement. Transmission efficiency is directly impacted by the planning for the earth-satellite access link and the inter-satellite link. Additionally, although the fundamental concept of SDN unified control enables the controller to communicate with and route network information with the on-board switch via OpenFlow, the time-varying satellite topology results in a large increase in link switching overhead. However, a large increase in link switching cost results from the satellite topology's time-varying nature. This problem model takes into account a variety of priority flow scenarios. For example, if just one service needs data transmission and there is only one ideal way, routing will be carried out immediately along the ideal path. The services will share links, however, if many services must be transmitted simultaneously. This will result in interference.

Dynamic priority ant colony routing algorithm : The DPAC algorithm can be divided into two main phases: dynamic path search and dynamic routing table update. Firstly, during the initialization phase of the algorithm, there exists a default set of topological connectivity relationships that ensure that satellites are connected in the initial or emergency state, and the paths in this phase are not optimal[8]. The paths in this phase are not optimal. Subsequently, during the dynamic path search phase, the DPAC algorithm will release a large number of ants to find the best path to different target nodes, thus completing the dynamic path path search process. Finally, the ant colony algorithm is in the dynamic routing table update phase. Due to the constant movement of satellite nodes and the changing spatial environment Due to the continuous movement of satellite nodes and the changing spatial environment, the best path obtained in the second stage may only be a local optimal solution. It is necessary to set a reasonable threshold to exit the search.

Multi-constraint multi-objective mode : In scenarios where MEO/LEO satellite networks are combined with ground-based networks, especially when switching network topologies. There is a load imbalance between the SDN central control node and the normal nodes and they are prone to congestion.The existing satellite network routing methods mainly focus on path length, topology maintenance and other improvements, but ignore the QoS status of the network. The existing satellite network routing methods focus on path length and topology maintenance, but ignore the QoS status of the network and fail to address the stability of data transmission[9].

A. Key performance considered by partial dynamic routings in SAGIN[10]–[18].

Scheme	Time Delay	Packet Loss Rate	Calculation	Throughput	Contribution to 6G-SAGIN
Multi-QoS routing [10]	Low	Low	Medium	High	High
Heuristic QoS routing [11]	Medium	Low	Medium	Low	Medium
Multi-constraint QoS routing algorithm [12]	Low	Low	Low	Low	High
Bandwidth-routing [13]	Medium	Low	Low	Medium	Medium
STAG routing [14]	Low	Medium	High	High	Medium
Admission Control routing [15]	Medium	Medium	Medium	Low	Medium
Priority-based routing algorithm [16]	Low	Low	Low	Low	High
Load-balanced routing [17]	Medium	Low	Low	Low	Medium
Queue State routing [18]	High	Low	low	Low	High

Fig. 4: Key performance considered by partial dynamic routings in SAGIN based on time delay, packet loss rate, computing time, and throughput (Their contribution to tackle routing problem in 6G-SAGIN)

IV. Simulation

This reports presents a dynamic priority ant colony routing algorithm for the SAGIN scenario. Terrestrial network nodes are served through the LEO/MEO two-layer satellite network that has been deployed with distributed controllers. The algorithm is based on QoS constrained optimization of the satellite network, firstly by using the concept of timing diagrams is based on QoS constrained optimization of satellite networks. The algorithm is based on the concept of time-series diagram, which firstly discretizes the satellite network model topology dynamically, then defines the satellite delay, residual bandwidth and link utilization metrics, and ensures the balance between different metrics in the SDN integrated network to meet the QoS requirements. The algorithm collects global nodes' latency, link status and bandwidth to calculate QoS status values, which can avoid excessive continuous data transmission through some highly loaded satellite nodes to transmit too much continuous data. This avoids the transmission of too much continuous data through some highly loaded satellite nodes. The proposed ant colony algorithm is effective in ensuring that effectively guarantees the QoS requirements of the integrated network in multiple business scenarios.

Based on the SDN-oriented integrated network scenario between space and earth, this simple proposes a ground base station via dynamic priority ant colony routing algorithm for LEO/MEO two-tier satellite networks. The algorithm is based on satellite network QoS. The algorithm is based on the QoS constraint optimization of satellite networks, firstly, the topology of the satellite network model is dynamically discretized by using the concept of timing diagram, secondly, the metrics of satellite delay, residual bandwidth and link utilization are defined, and the balance between reportnt metrics of SDN integrated networks is ensured by the cost function. The second is the definition of satellite delay, residual bandwidth and link utilization metrics, which ensure the balance between different metrics of the SDN integrated network and meet the QoS requirements through cost functions. Tools used: STK, NS3 and ONOS.

INPUT:

S_A : traffic flow A source node

D_A : traffic flow A destination node

S_B : traffic flow B source node

D_B : traffic flow B destination node

P_A : priority of traffic flow A

P_B : priority of traffic flow B

W_{t_o} : global topological initial weight at time t_0

P_{out} : set of alternative paths

A_k : Kth ant node

for A_k in P_{out}^{ants}

A_k starts from S and puts S into R_e

A_k searches the next node v_n from the neighboringnodes according to probability

1: **if** $v_n = v_d \ \&\& T \le T_{life}$

2: **exit**

3: **else**

4: Compute Q_{value}

5: **if** $Q_{t_i} \ge Q_{t_{i-1}}$

6: $\mu_{ij} \leftarrow \mu_{ij} + \Delta\mu_{ij}''$

7: $\mu_{ij} \leftarrow \mu_{ij} + \Delta\mu_{ij}'''$

8: **end if**

9: **if** $v_n \in R_e$

10: $A_k = v_{i-1}$ $\mu_{ij} \leftarrow (1-\theta)\mu_{ij} + \Delta\mu_{ij}'$ **go to** step 14

11: **else:** $\mu_{ij} \leftarrow (1-\theta)\mu_{ij} + \Delta\mu_{ij}'$ $T_{path} = T_{path} + t$ go to step 13

12: **if** $T_{path} + t \ge T_{life}$

13: drop A_k go to step 13

14: Set $i = i+1$ go to step 13

15: **end if**

16: **End for**

OutPut: The best DPAC path P_{ACO}

Fig. 5: Dynamic priority ant colony routing algorithm

Interaction of routing and flow control. :

Figure 6 Interaction of routing and flow control. As good routing keeps delay low, flow control allows more traffic into the network Routing interacts with flow control in determining these performance measures by means of a feedback mechanism shown in Fig. 6. When the traffic load offered by the external sites to the subnet is relatively low, it will be fully accepted into the network, that is,

Throughput = offered load

When the offered load is excessive, a portion will be rejected by the flow control algorithm and,

Throughput = offered load - rejected load

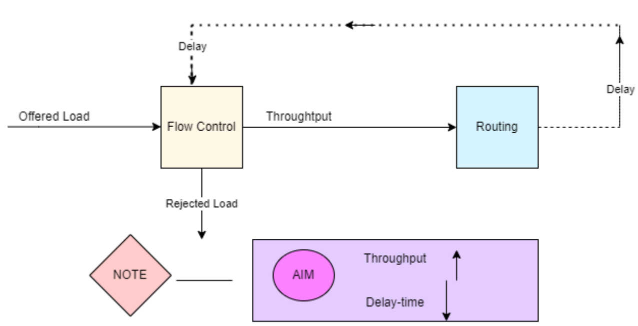

Fig. 6: Interaction of routing and flow control.

The traffic accepted into the network will experience an average delay per packet thatwill depend on the routes chosen by the routing algorithm. However, throughput will also be greatly affected (if only indirectly) by the routing algorithm because typical flow control schemes operate on the basis of striking a balance between throughput and delay (i.e., they start rejecting offered load when delay starts getting excessive). Therefore, as the routing algorithm is more successful in keeping delay low, the flow control algorithm allows more traffic into the network.

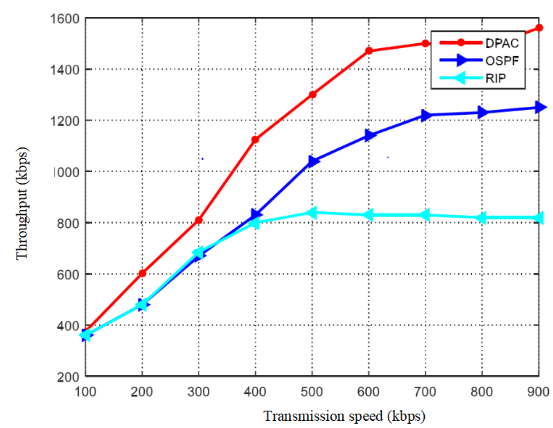

Fig. 7: SIMULATION

Therefore, it is necessary for the DPAC algorithm to set refresh cycles. The ants need to search again at each refresh cycle for the best path again at each update cycle. The specific refresh cycle time can be matched to the satellite topology update time. From this Fig.7, DPAC is more effective than Open Short Path First and Routing Information Protocol.

V. Conclusion

In preparation for the upcoming 6G era, the current terrestrial networks have evolved into space-air-ground integrated networks (SAGIN), which provide exceptionally high data rates, seamless network coverage, and ubiquitous intelligence for communications of applications and services. However, SAGIN's conventional communications still experience issues with data routing. Within Limited Domains (LDs), which are technical domains with consistent application of routing and other policies as enforced by the entity that governs the domain, addressing and routing innovations are now active. A lot of difficulties have been confronted by addressing and routing both within and between constrained domains. One of these, resulting from the deployment of satellite and vehicle networks, is support for extremely dynamic topologies. Current routing methods may experience stability issues due to the mobility of network nodes. Future routing solutions should also look towards supporting different addressing semantics that go beyond network locations. For future direction, I believe that the combination of DPAC and unsupervised machine learning will reduce routing problems in SAGIN.

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Dear Associate professor Du Bing, I would like to thank you for introducing this project to us which helped me to experience a new skill, a new knowledge, and also very helpful in the journey of becoming a good researcher.

VII. DESCRIPTION

Abbreviation	Description
SAGIN	Space-Air-Ground Integrated Network (SAGIN)
SDN	Software-defined networking
GEO)	Geostationary orbit
MEO)	Middle-earth orbit
LEO	Low-earth orbit
CDN	Content delivery network
DPAC	Dynamic priority ant colony
STK	Systems Tool Kit
ns-3	ns-3 has been developed to provide an open, extensible network simulation platform, for networking research and education. In brief, ns-3 provides models of how packet data networks work and perform, and provides a simulation engine for users to conduct simulation experiments
ONOS	Open Network Operating System

Fig. 8: Description.

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