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Study of Load Balancing Routing Algorithm for Low Earth Orbit Satellite Networks

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ABSTRACT: Now a day's Low Earth orbit satellite networks are used for IP based services. Satellite networks are required to support multimedia services. Delivering QoS guarantees to the users of LEO satellite networks is complicated since footprints of LEO satellites move as the satellites traverse their orbits, and thus, causing frequent user handovers between the satellites. In LEO satellite networks the traffic on the inter-satellite links (ISLs) also change with changes in the user-to-satellite traffic (which in turn changes due to the mobility of the satellites).Hence, traditional terrestrial routing protocols cannot be applied to broadband LEO satellite networks. To improve robustness and for load balancing in Low Earth orbit satellite networks a Cross-layer design and Ant-colony optimization based Load-balancing routing algorithm (CAL-LSN) is designed and implemented. CAL-LSN can utilize the information of the physical layer to make routing decision during the route construction phase. CAL-LSN uses mobile agents called *ants* for gathering the information of the nodes. ACO is well adapted to decentralized systems such as constellations of satellites because of the delays incurred by signalling information as it propagates through the network. Using CAL-LSN LEO satellite network performance is improved by balancing traffic load and increasing the packet delivery rate. Meanwhile, the end-to-end delay and delay jitter performance can meet the requirement of video transmission.

KEYWORDS: Ant-colony optimization; cross-layer design; LEO satellite networks; load balancing; Quality of Service; inter-satellite links

1 INTRODUCTION

1.1 LOW EARTH ORBIT SATELLITE NETWORK

Low Earth orbit satellite networks provide short round trip delay and are becoming increasingly important. Low Earth orbit satellite networks will be an integral part of next generation telecommunication infrastructures. To provide global coverage to more diverse user population, a number of Low Earth orbit satellite systems have been proposed. The LEO systems can provide both the areas with terrestrial wireless networks and those areas that lack wireless infrastructure. In the former case satellite system could interact with the terrestrial wireless network to absorb instantaneous traffic overload of terrestrial wireless network In other words mobile users would alternatively access both terrestrial or satellite network through dual mode handheld terminals. In later application area LEO satellite could cover regions where terrestrial wireless systems are economically infeasible due to rough terrain or insufficient user population. In order to provide continuous and seamless services to users regardless of where a particular user is located, LEO satellite networks will have satellite constellations with tens of satellites. These satellites will be equipped with sophisticated technologies such as on-board processing and inter-satellite links and are expected to provide the framework for robust and efficient universal communications. A Low Earth Orbit is any earth orbit of up to approximately 1,500 kilometers in altitude. At this altitude, orbit the earth in approximately 100-120 minutes. This low altitude provides small end to end delays and low power requirement for both satellites and terminals.

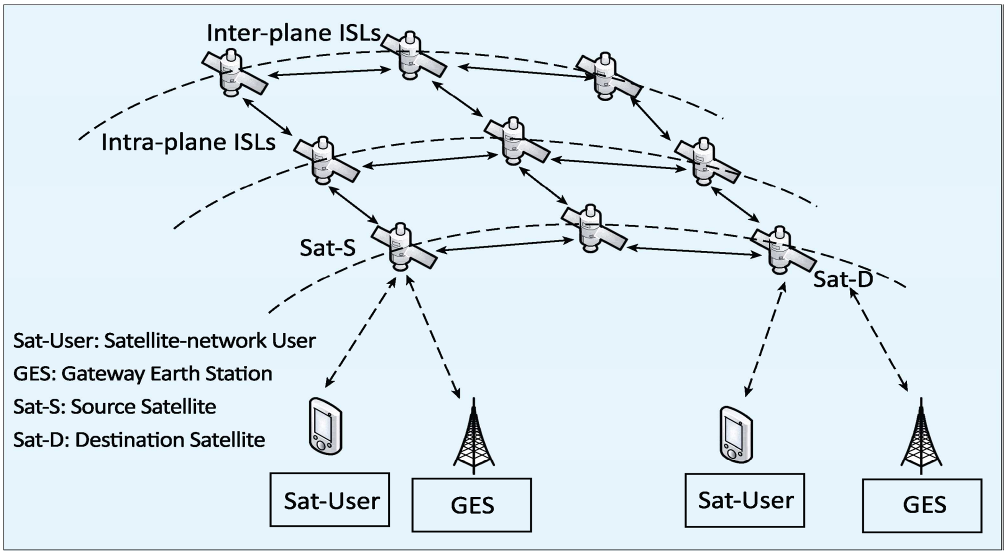

Fig.1.1 LEO satellite networks

1.2 CROSS LAYER DESIGN

Simple, yet effective, solutions which extend parts of the strict layering structure to system-wide CLD where stack wide layer interdependencies are designed and implemented to optimize overall network performance. As mentioned previously, the traditional way of designing a wireless manet or cellular network architecture, has been to identify each process or module and then assign them roles or requirements. Since each process or module has been treated separately, this approach has in many ways caused the research communities to split into different groups, where each group focus their resources on solving "their" problem the best possible way. The whole idea behind CLD is to combine the resources available in the different communities, and create a network which can be highly adoptive and QoS-efficient by sharing state information between different processes or modules in the system.

1.3 ANT COLONY OPTIMIZATION

The ant colony optimization algorithm (ACO), is a probabilistic technique for solving computational problems which can be reduced to finding good paths through graphs. In many ant species, ants walking from or to a food source, deposit on the ground a substance called *pheromone*. Other ants are able to smell this pheromone, and its presence influences the choice of their path, that is, they tend to follow strong pheromone concentrations. The pheromone deposited on the ground forms a pheromone trail, which allows the ants to find good sources of food that have been previously identified by other ants. Using random walks and pheromones within a ground containing one nest and one food source, the ants will leave the nest, find the food and come back to the nest. After some time, the way being used by the ants will converge to the shortest path.

2 ROUTING ALGORITHMS FOR LOW EARTH ORBIT SATELLITE NETWORK

As the LEO satellite moves along its orbit, it must service as many users that are in its coverage area, as possible. The effects of non-uniform geographical user traffic distributions in LEO satellite networks have not been investigated extensively. As explained in the previous sections, non-uniform user traffic load on the satellites may cause changes in the traffic on inter-satellite links, which may result in unexpected dropping of some of the user calls or packets. Which affects the delivery of guaranteed services to the users? Guaranteed services require that the packets of a call arrive within a pre-specified guaranteed delivery time and that the packets will not be discarded due to queue overflows. In a LEO satellite network, satellites and their individual coverage areas move relative to a fixed observer on Earth. To ensure that ongoing calls are not disrupted as a result of satellite movement, calls should be transferred or handed over to new satellites. Since two satellites are involved in a satellite handover, connection route should be modified to include the new satellite into the connection route. Designing an efficient routing algorithm for LEO satellite constellations is crucial for optimizing IP over Satellite (IPoS) network resources. Since there could be many shortest paths between two satellites, an efficient routing algorithm should provide better utilization of these paths. In LEO satellite networks the traffic on the inter-satellite links (ISLs) also change with changes in the user-to-satellite traffic (which in turn changes due to the mobility of the satellites). Hence, traditional terrestrial routing protocols cannot be applied to broadband LEO satellite networks. Although sufficient bandwidth may be available on a particular route at call set-up for a particular call, the same route may become congested in time due to the changes in access traffic loads which in turn are changing due to the mobility of the satellites. The focus in research in LEO satellite networks has been in providing successful handover to users as they transition from one satellite's coverage area to the coverage area of another.

There are following routing algorithms for LEO satellite networks:

2.1 Improved Ant Colony System (IACO)

An adaptive routing algorithm based on an Improved Ant Colony System (IACO) was made use of in LEO satellite networks. The original ant-colony algorithm in LEO satellite networks is improved with its own cyclical and regular characteristics. When IACO is made use of in the network, the end-to-end delay and delay jitter performance are poorer. When the number of users increases, IACO always tends to select the optimal path. This will make the load of the optimal path heavy.

2.2 Distributed QoS-based Algorithm (DQA)

DQA focuses on multi-objective QoS routing based on heuristic ant algorithm. It satisfy QoS parameters delay bound and avoid link congestion [10], it considers the handover between the satellite and the ground station so as to minimize the effect on the active connections.

2.3 Cross Layer Design and Ant Colony Optimization Based Load Balancing Routing Algorithm for Low Earth Orbit

Satellite Networks (**CAL-LSN**): This is a novel routing algorithm based on cross layer design for LEO satellite networks to improve the robustness of the networks. A multi-objective optimization model that considers the transmission delay, the residual bandwidth and the channel state is established. Ant-colony algorithm is utilized to solve this model to find the optimal path.

2.3.1 Goals Of CAL-LSN

High Throughput: Throughput is defined as the ratio of the number of all data packets delivered to the base station to the number of all sampled data packets. CAL-LSN can improve the throughput of the networks.

End-to-end delay and delay jitter: The average time taken by a data packet to arrive in the destination is known as end to end delay. Is the difference in end to end one-way delay between selected packets in a flow with any lost packets being ignored. The effect is sometimes referred to as jitter. End-to-end delay and delay jitter is improved.

Packet delivery rate: called Packet delivery rate. When CAL-LSN is used Packet delivery rate is increased.

Link utilization: The percentage of a network's bandwidth that is currently being consumed by network traffic is known as Link utilization. The link utilization is the highest when CAL-LSN is used.

2.3.2 Design Of CAL-LSN

As shown in Fig.2, Every satellite node has five modules.

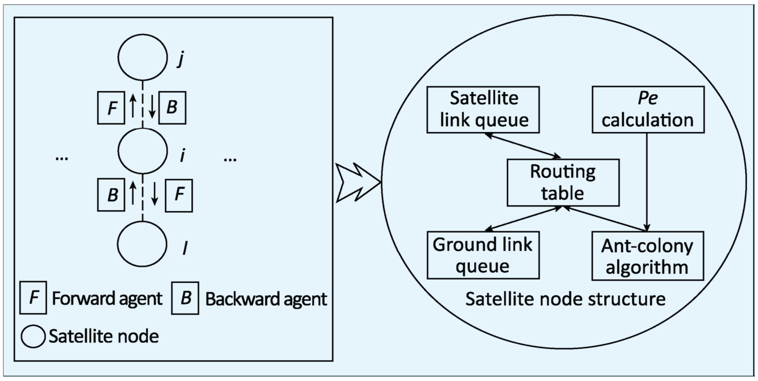

Fig 5.1 The mechanism of CAL-LSN

Ground link queue module is in charge of storing packets that interact with the ground station.

Satellite link queue module stores packets that interact with other satellite nodes in the network.

***Pe* calculation module** perceives the wireless link quality and calculates the error probability of each link.

Ant-colony algorithm module the result of *Pe* calculation module is the input of ant-colony algorithm module. This module can calculate the probability of sending data packets to adjacent satellite nodes.

Routing table module The value is saved in routing table module. There are two kinds of agents in CAL-LSN: forward agent and backward agent. The former travels through the satellite networks and collect routing information and the latter updates the routing table

2.3.3 MECHANISM OF CAL-LSN

To ensure the timeliness of packet transmission and to prevent network congestion, the cost of each link is defined as in Eq. (1).

$$\mathrm{cost}_{ij} = \omega_1 \times \frac{PD_{\min}}{PD_{ij}} + \omega_2 \times \frac{RB_{ij}}{RB_{\max}} \qquad (1)$$

For simplification, the residual bandwidth constraint and the delay constraint are equally important indications of link cost in CAL-LSN, so $\omega 1= \omega 2=0.5$. *PD*min stands for the minimum propagation delay of the satellite networks. *PDij* is the propagation delay of link (*i*, *j*) and *RBij* is the residual bandwidth of link (*i*, *j*). *RB*max stands for the maximum residual bandwidth.

The propagation delay of intra-satellite links and inter-satellite links is about 13.47 ms and 11.58×cos*j*° ms respectively, according to Ref. [14] .Where *j* is the value of satellite latitude. The inter-satellite links are closed when satellites are in the Polar Regions. According to the latitude threshold for Polar Regions, the value of *PD*min can be derived. The value of *RB*max is the bandwidth of satellite links and *RB*max= *BW*. In CAL-LSN, path *P*(src, des) should satisfy the following constraints for an application to begin and progress, where src refers to the source satellite, des refers to the destination satellite.

$$\begin{aligned} &\max \sum_{(i,j)\in P(\mathrm{src},\mathrm{des})}^{\mathrm{des}} \mathrm{cost}_{ij} \\ &\sum_{(i,j)\in P(\mathrm{src},\mathrm{des})}^{\mathrm{des}} TD_{ij} \leqslant De \\ &\min_{(i,j)\in P(\mathrm{src},\mathrm{des})} RB_{ij} \geqslant B \\ &\underset{(i,j)\in P(\mathrm{src},\mathrm{des})}{\forall\, \mathrm{link}(i,j)} \; Pe_{ij} \leqslant 10^{-6} \end{aligned} \qquad (2)$$

In Eq. (2), *i* and *j* stand for two satellite nodes in path *P*(src, des). According to Ref. [15], in order to ensure reliable data transmission, the error probability *Pe* should satisfy *Pe*≤10-6. *TDij* is the transmission delay of link (*i*, *j*). *De* stands for the maximum delay the LEO satellite networks can tolerant and *B* stands for the minimum bandwidth constraints. *TDij* and *RBij* can be calculated according to Eqs. (3) and (4).

$$TD_{ij} = PD_{ij} + QD_{ij} \qquad (3)$$

$$RB_{ij} = BW - Q_{ij} \qquad (4)$$

Where *QDij* is the queuing delay of link (*i*, *j*) and *Qij* is the mean queue length of link (*i*, *j*).

2.3.4 FORWARD AGENT BEHAVIOR

At the regular interval Δ*t*, a forward agent F*s*→*d* is launched at source satellite node *s* toward destination satellite node *d*. The topology of the satellite networks has the feature of regularity and periodicity. So the next hop which is near to the destination node will have a lager probability to be chosen. For node *s*, the probability to choose the next hop *j* is calculated according to Eq. (5).

$$\left(p_{sjd}\right)_{\text{agent}} = \frac{1/\text{Hop}_{jd}}{\sum_{j \in M} 1/\text{Hop}_{jd}} \quad (j \neq d) \qquad (5)$$

In Eq. (5), HOP*jd* stands for the minimum number of hops from node *j* to node *d* and *M* is the set of satellite nodes that are adjacent to satellite node *s*. Each forward agent has two lists. The $V_{v_0 \to v_m} = [v_0, v_1, \cdots, v_m]$ maintains the set of satellite nodes the forward agent passes and the list $T_{v_0 \to v_m} = [T_{v_0 \to v_1}, T_{v_1 \to v_2}, \cdots, T_{v_{m-1} \to v_m}]$ records the time the forward agent passes each node. At each intermediate node *i*, the forward agent uses the pseudo-random proportional selection rule [17], which adopts the strategy of deterministic rules combined with random selection. The forward agent *k* which is located at node *i* will choose the next node *j* through the following formula.

$$\left(p_{ijd}\right)_{\text{agent}} = \begin{cases} \dfrac{(p_{ijd})_{\text{data}}}{\sum_{j \in \text{table}_k} (p_{ijd})_{\text{data}}} & (\text{if } q \leqslant q_0) \\ 1/N & (\text{if } q > q_0) \end{cases} \qquad (6)$$

Here *q* is a random number which is even distribution in (0, 1), and *q*0 is a parameter (0<*q*0<1) whose size reflects the relative importance of using prior knowledge and exploring the new path. Table *k* represents the set of the next node which ant *k* can choose and *N* is the number of elements in table*k*. The function of table*k* is avoiding routing loops.

2.3.5 BACKWARD AGENT BEHAVIOR

Once the forward agent *Fs*→*d* reaches the destination satellite, it is terminated and the backward agent *Bd*→*s* is created. *Bd*→*s* copies the two lists from *Fs*→*d* and follows the identical path in the reverse direction. At each satellite node *Bd*→*s* passes, the probability for data packets to choose the next hop is updated. In Figure 2, suppose that one backward agent arrives at satellite node *i* from satellite node *j*. For satellite node *i*, the number of links accords with the number of ports. In the original ant-colony algorithm, the pheromone of the link between these two satellites is increased. Suppose that *r* is an arbitrary satellite node that is adjacent to satellite node *i* and *M*1 is the set of satellite nodes that are adjacent to satellite node *i*. The set *K* in CAL-LSN is defined as

$$K = \left\{ r, (Pe)_{ir} < 10^{-6}, r \neq j, r \in M_1 \right\} \qquad (7)$$

That is, *K* is the set of satellite nodes that satisfies (*Pe*)*ir*<10-6 except node *j*. *l* is one element of set *K* and *l* satisfies:

$$l \in K \cap \text{cost}_{il} = \max\left\{ \text{cost}_{ir}, r \in K \right\} \qquad (8)$$

The probability for data packets to choose the next hop is calculated according to Eqs. (9) and (11). Suppose that *T*update stands for the routing table update cycle. *h* is the number of backward ants one satellite node receives during this update interval. The value of *h* in Eqs. (9) and (11) returns to zero every fixed time interval.

$$(P_{ijd})_{\text{data}}|_{h+1} = \begin{cases} \rho\times(P_{ijd})_{\text{data}}|_h + (1-\rho) \\ \qquad (Pe)_{ij}|_h < 10^{-6} \\ \rho\times(P_{ijd})_{\text{data}}|_h \\ \qquad (Pe)_{ij}|_h \geqslant 10^{-6} \end{cases} \quad (9)$$

$$(p_{ijd})_{\text{data}}|_{h=0} = \frac{1/\text{Hop}_{jd}}{\sum_{j\in M_1} 1/\text{Hop}_{jd}} \quad (j\neq d) \quad (10)$$

$$\left(\underset{r\neq j}{p_{ird}}\right)_{\text{data}}|_{h+1} = \begin{cases} \rho\times(P_{ird})_{\text{data}}|_h + (1-\rho) & (Pe)_{ij}|_{h+1} \geqslant 10^{-6} \cap r = l \\ \rho\times(P_{ird})_{\text{data}}|_h & (Pe)_{ij}|_{h+1} \geqslant 10^{-6} \cap r\in K \cap r\neq l \\ \rho\times(P_{ird})_{\text{data}}|_h & (Pe)_{ij}|_h \geqslant 10^{-6} \cap r\notin K \\ \rho\times(P_{ird})_{\text{data}}|_h & (Pe)_{ij}|_h < 10^{-6} \end{cases}$$
$$(11)$$

$$\left(\underset{r\neq j}{p_{ird}}\right)_{\text{data}}|_{h=0} = \frac{1/\text{Hop}_{rd}}{\sum_{r\in M_1} 1/\text{Hop}_{rd}} \quad (r\neq d) \quad (12)$$

In Eqs. (9) and (11), ρ is the pheromone evaporation coefficient. In order to ensure that data packets will choose the link that its probability is strengthen, the value of ρ is discussed in this paper. Suppose that at the time satellite node *i* receives the *h*-th backward agent, the probability for data packets to choose link (*i*, *j*) and link (*i*, *l*) is *P*1 and *P*2 respectively. When node *i* receives the (*h*+1)-th backward agent, the value of (*pijd*) data is strengthen, so according to Eqs. (9) and (11)

$$(P_{ijd})_{\text{data}}|_{h+1} = \rho\times P_1 + (1-\rho) \quad (13)$$

$$(P_{ild})_{\text{data}}|_{h+1} = \rho\times P_2 \quad (14)$$

In order to ensure that data packets will choose the link that its probability is strengthen, the following conditions should be satisfied.

$$\rho\times P_1 + (1-\rho) > \rho\times P_2 \quad (15)$$

That is,

$$\left(\frac{1-\rho}{\rho}\right) > |P_2 - P_1| \quad (16)$$

If $\frac{1-\rho}{\rho}$ satisfies $\frac{1-\rho}{\rho}\geqslant 1$ Eq. (16) can be tenable regardless of the value of *P*1 and *P*2. $\frac{1-\rho}{\rho}\geqslant 1$ is equivalent to $\rho\leqslant 0.5$. So we can conclude that data packets will choose the link that its probability is strengthen if the value of ρ satisfies $\rho\leqslant 0.5$. n the basis of Ref. [12], we define an interval [min, max]. *x* satisfies even distribution in [min, max]. The relationship between *Pe* and *x* is as follows,

$$Pe = \lambda\times e^{-\lambda x} \quad (17)$$

where λ=1. In this paper, the value of *Pe* is made as the external input, $a = \ln\frac{1}{10^{-6}} \in$ min, max]. The interval [min, max] is defined considering satellite constellation characteristic In the light of the latitude of the satellite at time *t*, we define three areas. Let λ*u* reflects the probability of *Pe* larger than 10-6 in each area and lat*u*(*t*) denote the latitude of the satellite at time *t*, the definition of λ*u* is shown in Eqs. (18) and (19).

Inter-plane satellite links:

$$\lambda_u = \frac{\max - a}{\max - \min} = \begin{cases} 0.05 & -90^\circ < \mathrm{lat}_u(t) \leqslant -60^\circ \\ 0.1 & -60^\circ < \mathrm{lat}_u(t) \leqslant -30^\circ \\ & \vee\, 30^\circ < \mathrm{lat}_u(t) \leqslant 60^\circ \\ 0.15 & 60^\circ < \mathrm{lat}_u(t) \leqslant 90^\circ \end{cases} \quad (18)$$

Intra-plane satellite links

$$\lambda_u = \frac{\max - a}{\max - \min} = 0.15 \quad (19)$$

The average link utilization is calculated according to Eq. (20).

$$\mathrm{link\_}uti = \frac{\sum_{i=1}^{H}\sum_{j=1}^{4} S_{ij}}{4 \times H \times 1 \times 10^7} \quad (20)$$

Where *Sij* is the *j*-th port's actual transmission rate of satellite node *i*. *H* is the number of satellites over the whole constellation. An Iridium-like satellite constellation is considered for our study, so the value of *H* is 66.

3 Conclusion

The characteristics of the satellite links are discussed to improve the robustness of the LEO satellite networks. In order to perceive the conditions of the time-varying satellite channel, and improve the robustness of the network, CAL-LSN was proposed. In CAL-LSN, mobile agents are being used to gather routing information actively and cross-layer architecture is used. The network layer can make routing decisions based on link quality. Then, the optimization model was given. The model considered the minimum bandwidth constraint and the maximum delay the LEO satellite networks can tolerant as well as the error probability of the link. Thirdly, In order to make sure that data packets will choose the link on which the probability was strengthen, we are giving the update formula of the probability when data packets transmitted and discussed its key parameters. Finally, CAL-LSN can be compared with IACO and DQA. The simulation tool NS2 will be used. The performance of packet delivery, link utilization, the end-to-end delay of the network and delay jitter was compared respectively.

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