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Space-Terrestrial Integrated Mobility Management via Named Data Networking

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Abstract: In Future Space-Terrestrial Integrated Networks (FSTINs), mobility is the norm rather than the exception, the current TCP/IP architecture is not competent. As a promising future network architecture, Named Data Networking (NDN) can support content consumer mobility naturally, but the content producer mobility support remains a challenging problem. Most previous research simply considered this problem in terrestrial scenarios, which involve stable infrastructures to achieve node mobility management. In this paper, we consider the problem in an FSTIN scenario without special handover management infrastructures. Specifically, we propose a tracing-based producer mobility management scheme and an addressing-assisted forwarding method via NDN architecture. We formally describe Multi-Layered Satellite Networks via a Time Varying Graph model and define the foremost path calculating problem to calculate the route of space segment, as well as an algorithm that can function in both dense (connected) and sparse (delay/disruption tolerant) scenarios. Finally, we discuss the acceleration method that can improve the Space-Terrestrial Integrated forwarding efficiency. Performance evaluation demonstrates that the proposed scheme can support fast handover and efficient forwarding in the FSTIN scenario.

Key words: mobility management; space-terrestrial integrated network; NDN forwarding

1 Introduction

Changes in wireless networking design have benefited local "cellular" connectivity rather than the global interconnection. This model works well for terrestrial nodes especially desktop PCs that communicate with servers over wires but not for our increasingly wireless mobile world, especially for Future Space-Terrestrial Integrated Networks (FSTINs)[1–4]. In the upcoming "Space 2.0" era[1], a number of space nodes are equipped with powerful communication links, which can serve as either data producers/consumers or relay nodes. Such nodes make efficient Space-Terrestrial integrated communication possible.

As illustrated in Fig. 1, in such a scenario, mobility is the norm rather than the exception. As the TCP/IP architecture is not competent, so we need a location-independent communication model[5]. A common criticism is the so-called location-identity conflation problem. Despite the enormous body of work on device mobility to achieve location-independent communication, most known approaches fundamentally take one of three different approaches[5–9]: (1) indirection routing; (2) name resolution; and (3) name-based routing. Among them, name-based routing attempts to solve this problem from a new perspective by changing the mobility problem from "delivering packets to a Mobile Node (MN)" to "retrieving data produced by MNs".

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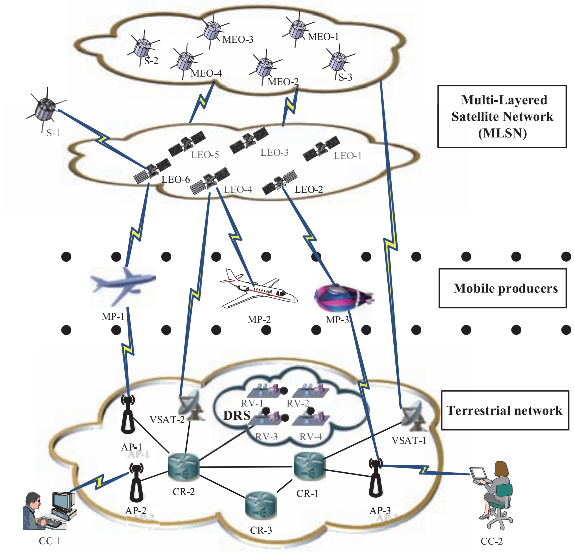

Fig. 1 A future space-terrestrial integrated network.

Named Data Networking (NDN)[10] is a promising future internet architecture that changes the network communication model from point-to-point packet delivery to named data retrieval without concern for the exact locations where the data resides in. As a newly proposed network architecture, NDN has drawn much attention from networking researchers and has been applied in several fields, such as vehicular networking[11] and video streaming[12].

The NDN architecture naturally supports consumer mobility through its stateful forwarding plane and the receiver-driven paradigm. When a consumer changes its Attachment Point (AP), it needs to reissue the unsatisfied Interests. Although the retransmission of Interests may lead to additional latency, it does not need to perform any location registration or update such as IP mobility management. However, the content producer mobility problem remains an active research topic[5–8].

Producer mobility leads to frequent routing update and low routing aggregation due to the locator/identifier binding properties. In NDN, data names are used for both routing of Interests and data identifying. Once a name changes, all relevant Content Routers (CRs) need to update their Forwarding Information Bases (FIBs) for the correct forwarding of Interests. Subsequently, the convergence time may be too long for real-time applications in highly dynamic scenarios. Furthermore, the number of routing entries in CRs increases linearly with mobility events, which can cause serious routing aggregation and scalability problems. The quantitative comparison results[5] suggest that pure name-based routing may be suitable for highly aggregatable content that moves infrequently but may need to be augmented with addressing-assisted approaches to handle device mobility for highly dynamic scenarios, such as FSTINs.

Although many works have attempted to address the producer mobility problem[6], little prior research has been done regarding this problem in FSTINs. Previous studies typically considered terrestrial scenarios, especially cellular networks with stable infrastructure where the infrastructure is static in the perspective of MNs. However, in FSTINs, all space-nodes are moving all the time. Pure terrestrial networks fail to provide globally "anywhere and anytime" support for near-earth aircraft due to their intrinsic "local" nature and limited coverage, but Multi-Layered Satellite Networks (MLSNs) can address these limitations.

In tracing-based mobility solutions[6, 8], whenever a Mobile Producer (MP) changes its AP, it needs to inform its Rendezvous (RV) to create a "breadcrumb trail" that can be followed by Interest to reach it. This process can be referred to as an Attachment Update (AU), and it does not need to perform any location registration or update operation[13]. Existing solutions simply consider these situations that AUs occur between non-moving APs that reside in a terrestrial network, e.g., MP-1 moves from AP-2 to AP-1 (Fig. 2, green dashed line).

In such an AU, the forwarding path (P-1) on which the AU packet will be routed is considered a known condition, just as most existing solutions. However, such

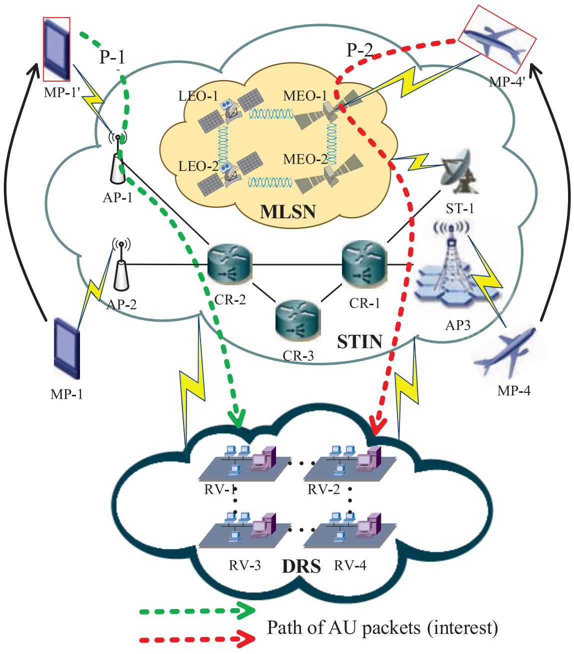

Fig. 2 Illustration of producer mobility in FSTIN.

an assumption will not hold if the current AP is also a space node. In the AU at which MP-4' AP is changed from AP-3 to MEO-1, P-2 will cross the MLSN where the MEO-1 resides in. In MLSNs, all links are switched frequently, and how such special Interest packets should be routed via time-varying route calculation remains a challenging problem (see Section 4.1 for details).

In this paper, we focus on Space-Terrestrial Integrated Mobility Supporting in NDN. The main contributions are summarized as follows:

- We propose a tracing-based producer mobility management scheme with Distributed Rendezvous System (DRS) to achieve Space-Terrestrial Integrated Mobility Support in NDN.
- We propose a Space-Terrestrial integrated forwarding method via NDN and an acceleration method, to help achieve globally "anywhere-anytime" communication.
- We formally describe MLSNs via a Time Varying Graph (TVG) model and define the foremost path calculation problem, as well as an algorithm that can adaptively work in both dense (connected) and sparse (delay/disruption tolerant) scenarios.

2 Basic Design

This section presents a tracing-based producer mobility management scheme via NDN for highly dynamic scenarios. In particular, we focus on Space-Terrestrial Integrated scenarios, as shown in Fig. 1. We partly borrow the ideas of Refs. [8, 9]. RVs are used to guarantee the global reachability of MPs and all RVs form a DRS. Each object has a unique prefix and a hierarchical name. The data's order of magnitude may be too high to process them separately in FIB. We store a soft-state in tFIB[9]. For long-term relocation of data producers, data need to be republished by using the prefix of its current RV to avoid long-term path stretching. We define a special traceable Interest packet, namely, AU Packet (AUP), and the specific structure is shown in Fig. 3.

AUP
RV-name
AUP-flag
Trace-name
Source-routing
Other selectors
Nonce
Acceleration-ctr
Guiders

Interest packet
Name
Source-routing
Other selectors (order preference, exclude filter ···)
Nonce
Acceleration-ctr
Guiders

Fig. 3 AUP and modified Interest packet structure.

"RV-name" is used to lead advancing AUP toward its corresponding RV. "AUP-flag" is used to indicate whether the packet is an AUP or not. The specific processes are described in Section 3. "Trace-name" indicates which Interest will be traced, and it should be exactly the same as the data name. Notably, "data name" is not restricted to a piece of content, and it may be an aggregation one. "Source-routing" field is used to carry the route that the AUP will follow if it exists. "Acceleration-ctr" field is optional. A typical MP mobility management process is shown in Fig. 4.

The steps are as follows:

- Step 1. MP-4 sends one or more AUPs to its RV after its AP has been changed from AP-1 to LEO-1.
- Step 2. The following Interest packet will still be forwarded towards AP-1. Until this moment, Content Consumer (CC-1) is not aware of this mobility event.
- Step 3. The Interest packets will trace the AUP at one CR, e.g., CR-1.
- Step 4. The following Interests will be forwarded towards MP-4 along the traced path, as well as the unsatisfied Interests that have been sent out before tracing.
- Step 5. MP-4 sends data packet(s) back to CC-1 along the reverse path of Interests.

RVs do not need to participate in producer/consumer communications, and they act as the rendezvous of AUPs and the unsatisfied Interests. We then need to address the problem of how AUP can be forwarded in the space segment, especially in MLSNs.

3 Space-Terrestrial Integrated Forwarding

This section presents the addressing-assisted forwarding method in NDN. In MLSNs, all links are time-related, and

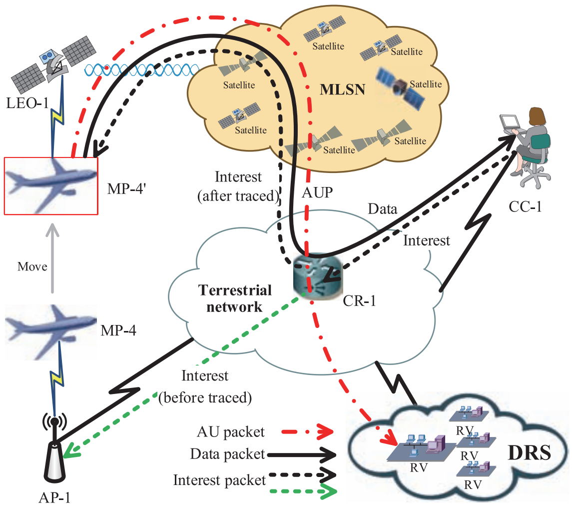

Fig. 4 Illustration of MP mobility management process.

no stable infrastructure exists. The CRs will need to update their FIBs frequently if pure name-based forwarding is directly used. We allocate each satellite with a globally reachable name prefix and then calculate the source route of the space segment. The source route will then be attached to the selector field to assist the forwarding process. The modified forwarding process is shown in Fig. 5.

Processes 1–4 are the same as the processes in the original NDN architecture. Process 5 is used to assess whether the packet is an Interest or an AUP. If it is a miss, then it is suppressed and we proceed to process 11. Otherwise process 6 extracts the "trace name" that has been attached in the selector fields, which will be used in the next process. Process 7 generates the correspondence between "trace-name" and "interface". The former is the globally reachable prefix (addressing-assisted), and the latter is the interface through which the data packet(s) can be sent back. The added or modified tFIB entry can be used to guide the following forwarding process. The corresponding Interests will move toward the current AP and finally reach the MP. Once process 7 is completed, the AUP will be suppressed because the AUP has been forwarded to its RV through a standard process (e.g., processes 1–4). Our method will not increase the communication burden of CR in terrestrial networks, and the additional computation cost is very small. In most cases, these Interest packets are regular ones and the additional cost is one logical judgment, as in process 5. In MLSNs, the return value of process 3 is "miss" for most packets due to the above analyses. We propose the addressing-assisted forwarding processes. In process 8, if the node is not a satellite, then a "NACK" message is returned. Otherwise, we move on to process 11 to extract an attached source route. If process 11 returns "hit", then we proceed to process 13, otherwise, we move to process 12 and calculate the source route. If process 13 returns "miss", that is, the packet is an Interest, then we move to process 4. Otherwise, we advance to process 14 and forwards the AUP without adding an entry in the Pending Interest Table (PIT) to reduce entries.

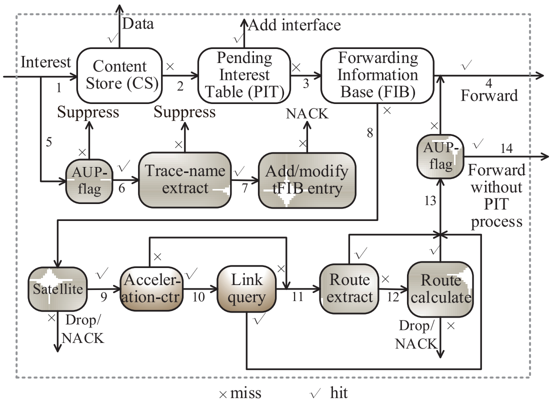

Fig. 5 The modified forwarding process.

4 Routing of MLSNs

In MLSNs, links switch frequently which results in a time-varying network topology whose characteristics are in accordance with Temporal Networks[14]. In this section, we characterize the time-varying characteristics of MLSNs via a TVG model[15] and then solve the dynamic routing problem from the perspective of edge changes.

4.1 Problem statement and definitions

Assume that the time is divided into discrete and equal time slots, such as $T=\{t_1,t_2,\cdots,t_n\}$. Let $V=\{v_1,v_2,\cdots,v_n\}$ be the set of all individual nodes in the network (which represents the set of satellites or other cyclical nodes if needed), then $G=\{V,E\}$ is the traditional static graph, but it cannot represent the information of time dimension. We further define $\mathcal{G}=(G,V,\mathcal{T},\rho,\zeta)$, a TVG of G, in which, $\mathcal{T}\subseteq T$ is the cycle of $\mathcal{G}$ and MLSNs; $\rho{:}E\times\mathcal{T}\rightarrow\{0{,}1\}$ is called presence function, and it indicates whether a given edge is available at a given time t; $\zeta{:}E\times\mathcal{T}\rightarrow\mathbb{T}$ is called latency function, and it indicates the time for one Maximum Transmission Unit (MTU) to cross a given edge if starting at a given time t (the latency of an edge varies with time); $\mathcal{L}\in\mathbb{N}^{+}$ represents the time-labeling of one edge, then $\mathcal{L}_{i+1}-\mathcal{L}_i\geqslant 2\zeta$ according to the "active-time" constraint of edges. $\mathcal{G}_{\mathcal{L}}=(V,E(\mathcal{L}))$ represents the $\mathcal{L}$-th static instance, where $E(\mathcal{L})$ represents the edges with label $\mathcal{L}$ (which could be empty) in G. $|n|$ represents the number of vertices, $|m|$ represents the number of edges and $|\mathcal{L}|$ represents the number of labels. The number of time edges in $\mathcal{G}$ is $|m_{\mathcal{L}}|=|m|\times|\mathcal{L}|$. If $\rho[t_a,t_b)(e)=1$, then for $\forall t\in[t_a,t_b)$ and $\forall e\in E$, $\rho(e)\equiv 1$. We use $\mathcal{G}'=\mathcal{G}[t_a,t_b)$ to represent the subgraph of $\mathcal{G}$ in $\mathcal{T}'=\mathcal{T}\cap[t_a,t_b)$.

Definition 1 P is a time-related route in $\mathcal{G}$, iff there is an edge sequence $\{e_1,e_2,\cdots,e_k\}$ in G, for $\forall i<k$, $\{\rho(e_i,t_i)=1\wedge t_{i+1}\geqslant t_i+\zeta(e_i,t_i)\wedge\rho_{[t_i,t_i+\zeta(e_i,t_i))}(e_i)=1\}$, where t_i is the depart time and t_k is the arrival time of P, also denoted as $d(P)$ and $a(P)$, respectively. The actual arrival time is $t_k+\zeta_k$ due to the presence of transmission delay.

Property. P can be used for data transmission.

Proof For $\forall i<k$, e_i can allow one MTU cross it due to the defined latency function. The restricted condition

$\{\rho(e_i,t_i) = 1 \wedge \rho_{[t_i,t_i+\zeta(e_i,t_i))}(e_i) = 1\}$ can guarantee the availability of $\forall e_i \in P$, as well as its capacity, and the restricted condition $\{\rho(e_i,t_i) = 1 \wedge t_{i+1} \geqslant t_i = 1\}$ can guarantee that all edges are arranged strictly in non-descending time. That is, we cannot use such a time edge to transmit data that are only present in the past. ■

Define $\mathcal{P}$ as the set of P in $\mathcal{G}$ and $\mathcal{P}(u,v) \subseteq \mathcal{P}$ as the set of P which departs from u and arrives at v. We define it as direct path if P resides in one $\mathcal{G}_{\mathcal{L}}$, otherwise we define it as indirect path.

The propagation delay of P is defined as

$$\zeta(P) = \sum_{1 \leqslant i \leqslant k} \zeta(e_i) \tag{1}$$

Notably, the availability of $P(u,v)$ does not mean that $P(v,u)$ exists, because the paths and edges are both time-related. As illustrated in Fig. 6, there exists a path $P(u,v) = \{(ua,1),(av,4)\}$, but $P(v,u) = \varnothing$. “[1, 2)” and “[4, 6)” denote the active time of the corresponding edges.

Definition 2 $P(u,v)$ is a foremost path at time t, if Formulae (2), (3), and (4) hold.

$$d(P) \geqslant t \tag{2}$$

$$a(P) = \min\{a(P') | P' \in \mathcal{P}\} \tag{3}$$

$$\zeta(P) = \min\{\zeta(P') | P' \in \mathcal{P}\} \tag{4}$$

If there is no direct path in any $\mathcal{G}_{\mathcal{L}}$, e.g., in sparse scenarios, then the indirect path is the foremost one whose $a(P)$ is the earliest given that Formula (4) is a weak constraint. For dense scenarios, one or more direct paths may exist, then Formula (4) is a strong constraint that adds complexity to the problem.

4.2 Dynamic algorithm based on TVG

We design an algorithm (Algorithm 1) that can efficiently calculate the foremost path that starts from source node $s \in V$ to destination node $v \in V \backslash \{s\}$ and adapt both sparse and dense scenarios automatically. We assume that each node corresponds with one satellite and the edges represent interactions between them over time. Every satellite can know the time-varying corresponding satellites of all RVs via the CP[16] method.

Theorem The algorithm can correctly output the foremost path–$P(u,v)$ given the required inputs.

Proof To ensure the correctness of this algorithm, $d[v] = \zeta(s,v)$ for each node $v \in Q$, at the start of each

Algorithm 1

```
1: //Initialization
2: $t \leftarrow t_{\text{start}}, \mathcal{L}'_{\max} \leftarrow TTL + t_{\text{start}} + 1$
3: for each $v \in V \backslash \{s\}$ do
4:     $p[v] \leftarrow \phi$
5:     $a[v] \leftarrow \infty$
6:     $d[v] \leftarrow \infty$
7: end for
8: $d[s] \leftarrow 0$
9: Initialize queue $Q$
10: In-queue $(Q,s)$
11: //Calculate the precursor time nodes and $\zeta(P)$
12: While $d \notin Q$ and $t \neq \mathcal{L}'_{\max}$ do
13:     for each $u \in Q$ do
14:         Out-queue $(Q)$
15:         for each $(u,v) \in E(t)$ do
16:             if $p[v] = \phi$ then
17:             $p[v] \leftarrow u$
18:             $a[v] \leftarrow t$
19:             $d[v] = d[u] + \zeta(u,v)$
20:                 else if $a[v] = t$ then
21:                     Relax $(u,v,d[v])$
22:                 end if
23:             In-queue $(Q,v)$
24:             end if
25:         end for
26:     end for
27: $t$++
28: end while
```

iteration of the while loop between lines 12 and 28. That is, we must prove that Formula (5) always holds when $\forall u \in V$ is added to queue Q.

$$d[u] = \zeta(s,u) \tag{5}$$

At time t_{start}, $d[s] = \zeta(s,s) = 0$ must hold because $Q = \{s\}$. In each iteration, let u be the first node that Formula (5) will not hold when it is added to queue Q at time t. We must have $u \neq s$ and $Q \neq \phi$. One or more paths must be available from s to u, and they should contain $P(s,u)$. Otherwise, $d[u] = \zeta(s,u) = \infty$ by the non-path property, which may violate our assumption.

We further suppose another path from s to u, which satisfies $a(P') < a(P)$, that is, $d'[u] < d[u]$. At time $t' < t$, there must be another time-edge (w,u,t'), which satisfies $w \in Q, u \notin Q$. Thus, the algorithm will add u to queue Q at $t' < t$, which will violate our initial assumption.

We conclude that $d[u] = \zeta(s,u)$ when node v is added to queue Q, and this equality is maintained at all times thereafter.

At termination, $Q = \phi$, which indicates that all nodes are in-queue and out-queue once. Consequently, $d[u] = \zeta(s,u)$ for all nodes $u \in Q$ to ensure the correctness of the algorithm. ■

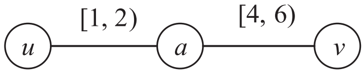

Fig. 6 Illustration of time-related path.

Under the worst case, all nodes will be added to queue Q, until the $(\mathcal{L}^{'}_{\max})$-th iteration. Meanwhile, the while loop between lines 12 and 28 will be executed $O(\mathcal{L}^{'}_{\max})$ times. The algorithm will traverse $O(n)$ nodes in each iteration. The complexity of relax and queue management is $O(n\log n)$ based on a modified Fibonacci heap structure. The complexity of one iteration is $O(n^2\log n(1+2+\cdots+\mathcal{L}^{'}_{\max}))=O(n^2(\log n)\,(\mathcal{L}^{'}_{\max})^2)$. The additional accumulation factor is $O(m_{\mathcal{L}})$ given that each time-edge is only accessed once. In summary, the overall time complexity is $O(n(\log n)\,(\mathcal{L}^{'}_{\max})^3+m_{\mathcal{L}})$.

During actual route calculations, if $\mathcal{G}_{\mathcal{L}}$ is connected at time t (that is, a direct path exists), then the time complexity is $O(n(\log n)+m)$. By contrast, $\mathcal{G}_{\mathcal{L}}$ is not connected, so we can control $\mathcal{L}^{'}_{\max}$ to a small positive integer number through the TTL (Time To Live) value in line 2. By doing so, the algorithm can converge after several iterations. The route calculation is performed for each packet which has a time constraint, and the algorithm can process a subgraph $\mathcal{G}'=\mathcal{G}_{[t_a,t_b)}$. Subsequently, the time complexity is $O(n(\log n)+m_{\mathcal{L}})$.

5 Discussion

In this section, we discuss the scalability and robustness of the Space-Terrestrial Integrated Mobility Supporting method and acceleration method.

5.1 Scalability

We discuss the scalability issues of mobility management, routing, and forwarding planes.

- Mobility Management: As a tracing-based solution, our method has weak management features and does not change the hierarchical architecture of NDN. Our method does not require an additional system to store MP's current position information, instead, these CRs that reside on the path from MP to RV need to add an entry in their tFIBs. This operation has a complexity of $O(n)$, where n is the number of mobility events. Then, an important question is how to store all the trace status. Fortunately, some studies[17, 18] have conducted in-depth research on how to design scalable and fast PIT, as well as CS and FIB. Thus, our method is scalable and can evolve with NDN architecture.

- Routing and Forwarding: Our addressing-assisted routing method does not lead to additional FIB updating in CRs and tFIB updating is run on separate threads. An important question is how the source-route of space-segments can be calculated efficiently. As analyzed in Section 4.2, our algorithm has a time complexity of $O(n(\log n)+m)$ for connected networks and $O(n(\log n)+m_{\mathcal{L}})$ for Delay Tolerant Networks (DTNs).

5.2 Robustness

In our scheme, the RVs do not participate in producer/consumer communications but simply act as the rendezvous of AUPs and the unsatisfied Interests. Therefore, they are pseudo-anchors, and will not suffer from single-point failures and attacks. Furthermore, we can adopt the distributed RV system to improve robustness.

5.3 Acceleration control

As illustrated in Fig. 5, processes 9 and 10 are used to control the acceleration operations. Our consideration is that, for a CR, (e.g., a satellite), a high priority link may exist regardless of the FIB at some time point or periods. Specifically, for a satellite, if a space-terrestrial link is present, which is connected to terrestrial-CRs, then this link will be the primary one, as illustrated in Fig. 7. The original path from MP-1 to CC-1 at this time is S1→S2→S3→CR-1 (the green dashed line). However, if we set an acceleration flag in S2, then the path will be S1→S2→CR-3→CR-1 (the red dashed line). Thus, we can prioritize to the use of satellite-ground links.

6 Performance Evaluation

6.1 Scenario description

We construct the terrestrial segment as illustrated in Fig. 1 and set one RV. We set the MLSN according to the "Iridium NEXT" project which started in 2016[19]. The link rate is set to 10 Mbps. The specific constellation parameters are shown in Table 1.

6.2 Average handover latency

We define the handover latency as the time duration that one AUP is traced at the new AP. We adopt 10 aircrafts to serve as MPs and 100 CCs distributed in the scenario. We then evaluate the average handover latency by varying the

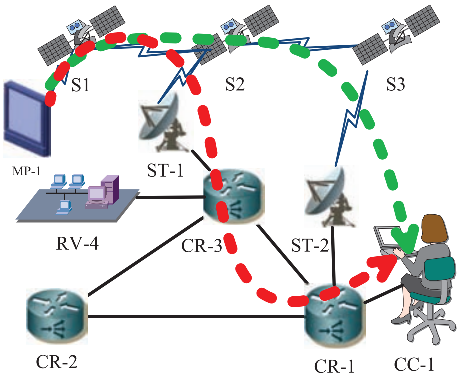

Fig. 7 Illustration of acceleration method.

Table 1 Constellation parameters.

Type	Number	Period (min)	Altitude (km)
MEO[20]	2×5	360	10 390
LEO[19]	6×11	100	780
Type	**Inclination**	**RAAN**	**True anomaly**
MEO[20]	45°/135°	Interval 72°	-
LEO[19]	86.4°	Interval 45°	Interval 60°

network load rate from 0.1 to 1.0. The results are shown in Fig. 8.

The average handover latency of space to terrestrial is the lowest, and the value varies from 70 to 80 when the network load rate changes from 0.1 to 1.0. The acceleration method can reduce the average handover latency by about 10%–16% under network load from 0.1 to 1.0 in the handover from terrestrial to space.

6.3 Forwarding performance

We store 1 000 different contents in each MP, and the average size of these contents is 1 Mb. Ten CCs are allocated to fetch back these contents from the corresponding MP. Subsequently, we evaluate the forwarding performance. The results are shown in Fig. 9.

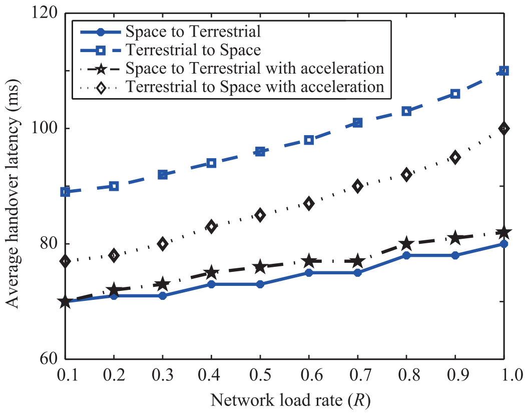

Fig. 8 Average handover latency vs network load rate.

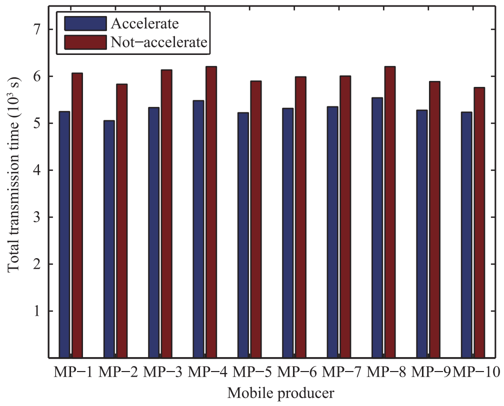

Fig. 9 Total transmission time of different strategies.

The total transmission time of different MPs demonstrates a slightly difference. However, the acceleration method can obtain speedup ratios from 0.09 to 0.134 and the average speedup ratio of 10 MPs is 0.115.

We vary the network load rate from 0.1 to 0.8, and evaluate the average transmission time under two different strategies: acceleration and not-acceleration. The results are shown in Fig. 10.

When $R \leqslant 0.5$, the average transmission time increases slowly. We then vary the network load rate from 0.1 to 0.8 and evaluate the PIT aggregation performance from the perspective of aggregation percentage. We use K to denote the aggregation number of PIT, and the results are shown in Fig. 11. Most packages can benefit from PIT aggregation even in the case of heavy network load. The non-aggregation rate is 15%–28%. We observe only 6%–8% entries when K=4. This is because we only allocate three interfaces to these CRs in terrestrial networks.

7 Conclusion

In this paper, we propose a Space-Terrestrial integrated

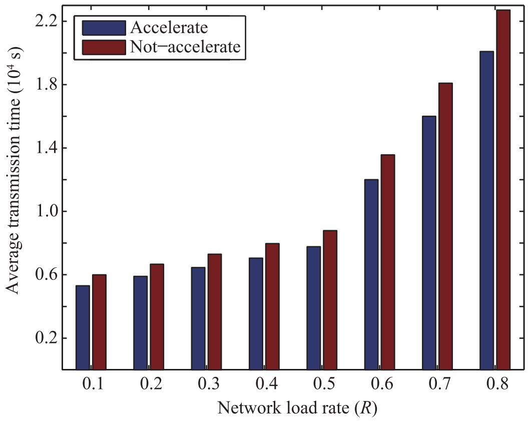

Fig. 10 Average transmission time vs network load rate.

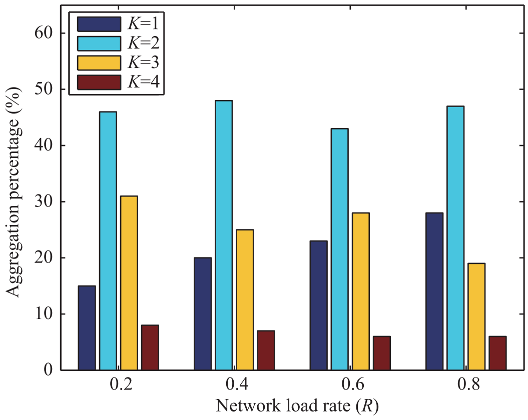

Fig. 11 PIT aggregation percentage vs network load rate.

mobility support method based on NDN architecture to assist Space-Terrestrial integrated cooperative communication in FSTIN scenarios. We first describe the FSTIN scenario and analyze the producer mobility problem. We then design a tracing-based producer mobility management scheme to reduce the FIB update operations in CRs, as well as an addressing-assisted forwarding method that can leverage NDN's stateful forwarding plane. Moreover, we formally describe MLSNs via a TVG model and define the foremost path calculating problem, as well as an efficient algorithm. We also discuss the scalability and robustness of the space-terrestrial integrated mobility supporting method, as well as an acceleration control method. Finally, we perform extensive evaluations to verify the handover latency and forwarding efficiency of our scheme.

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