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When Every Cell Must Speak: Signaling-aware Beam Hopping in LEO Satellite Networks

KTH Vetenskap och Konst

3D-NET 3D NETworks for 6G Mobile Communication Applications

SMART 6G SAT

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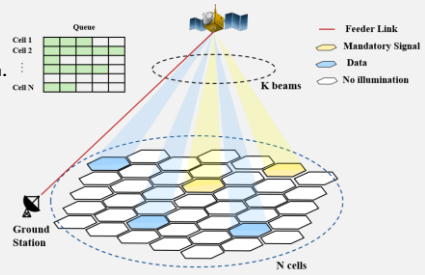
1 Why Beam Hopping?

Many cells. Few beams. Changing demand.

- LEO traffic demand is highly non-uniform and time-varying.
- A satellite may cover many cells, but can illuminate only a few at a time.
- Beam hopping dynamically directs scarce beam resources where traffic is needed.
- **Hidden problem:** Geometric coverage **does not guarantee a timely opportunity** to access the network.

2 Hidden Cost of Keeping a Cell Accessible

- **Coverage does not guarantee accessibility**: user can access the network only when illuminated at the required signaling occasion.
- **Common/Mandatory Signaling** include SSB, SIB1/SIB19, paging, random access messages that enable discovery and initial access of the terminals.
- Accessibility consumes scarce beam time creating a direct trade-off between **access inclusiveness** and **traffic efficiency**.



- Even a quiet cell with no user traffic still needs a beam scheduled to remain accessible.

3 What is Innovative?

- **Beyond traffic-driven Beam Hopping**: scheduling beams to preserve recurring access opportunities.
- **Accessibility by design**: a signaling-aware, access-inclusive scheduler that explicitly protects mandatory signaling.
- **Beyond throughput KPIs**: new access-centric metrics measure signaling violations, access delay, and cell revisit behavior.

4 Sustainability Relevance

Social Sustainability – Leave no cell unreachable

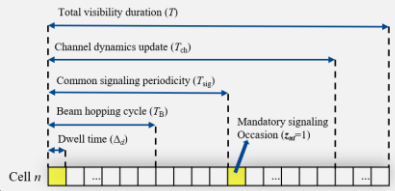
Equal access rights to users in sparse, remote, or maritime cells to discover and access the network.

- **Make inclusion resource-efficient:** Control the cost of accessibility by jointly tuning dwell time, signaling periodicity, and beam scheduling.
- **Inclusive access. Efficient resources. Sustainable 6G NTN.**

5 How a missed signaling burst impacts access?

Dwell Time
Minimum beam illumination interval

Signaling Periodicity
Interval between mandatory signaling occasions



Mandatory Signaling Violation (MSV)
Missed illumination of a Signaling occasion

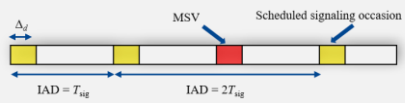
Initial Access Delay (IAD)
Gap between successful access bursts

Cell Revisit Time (CRT)
Time between cell illuminations

Traffic Satisfaction
Measure of unmet demand

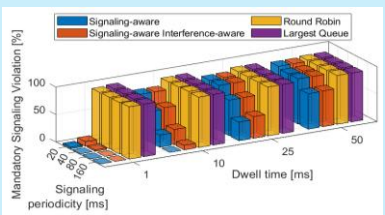
Resource utilization
Measure of unused capacity

Access inclusiveness | **Traffic efficiency**

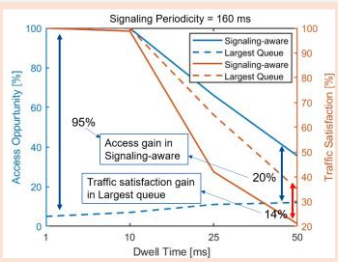


- **Successful signaling:** IAD remains equal to the nominal signaling periodicity.
- **Missed signaling:** The access is delayed, increasing IAD by integer multiples of the signaling periodicity.

6 Key Results



- **Accessibility improves:** Signaling-aware scheduling reduces missed access opportunities.



- **Inclusion has a cost:** Protecting low-demand cells creates an accessibility–efficiency trade-off.
- **The trade-off is controllable:** Dwell time, signaling periodicity, and scheduling policy tune the balance.

7 Key Takeaways

- **Coverage is not enough — every cell needs a timely chance to connect.**
- From traffic-driven to **access-driven beam hopping.**
- **Accessibility has a quantifiable cost:** Protecting signaling consumes beam time and exposes the price of inclusion.
- **Industry & standards impact:** Provides evidence to support **3GPP-oriented recommendations** on adaptive signaling periodicity for beam-hopping NTN.
- A practical path towards **socially sustainable 6G NTN** connectivity.

Let's Connect:

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