ENI PoC #17: Intelligent Satellite-Terrestrial Integration Network Architecture Progress Update

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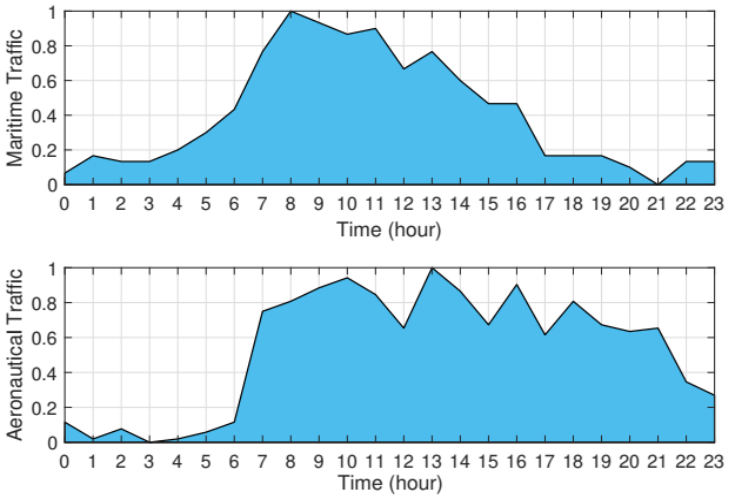
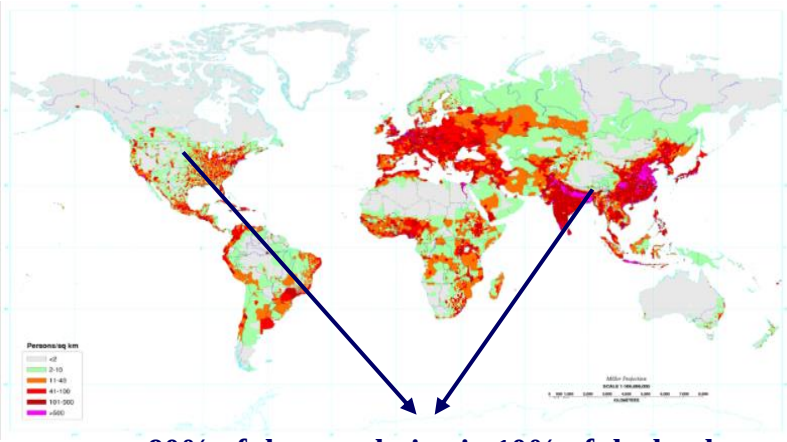
ENI PoC project #17: Intelligent Satellite-Terrestrial Integration Network Architecture

Spatial-temporal uneven distribution of satellite traffic

temporal non-uniformity

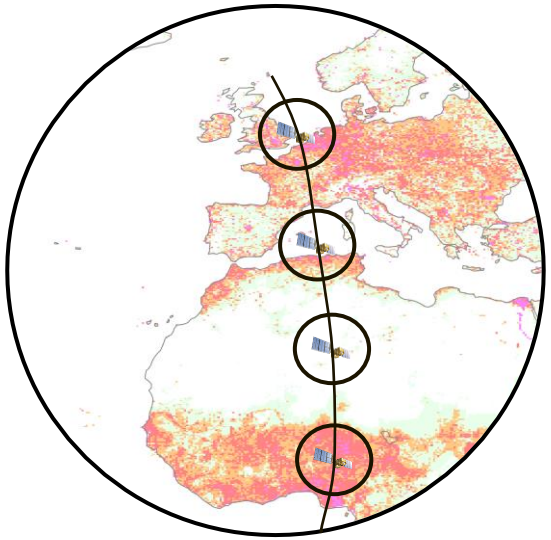


spatial non-uniformity



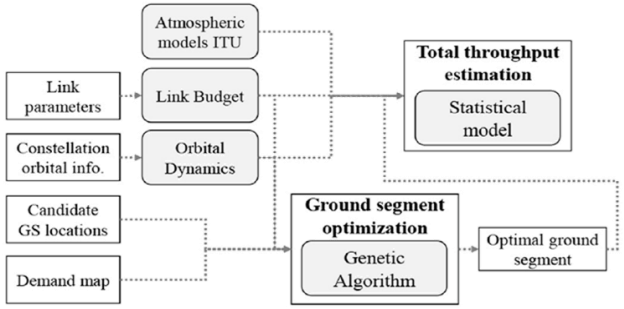
90% of the population in 10% of the land

satellite mobility



A Technical Comparison of Three Low Earth Orbit Satellite Constellation Systems to Provide Global Broadband

Inigo del Portillo[a,*], Bruce G. Cameron[b], Edward F. Crawley[c]

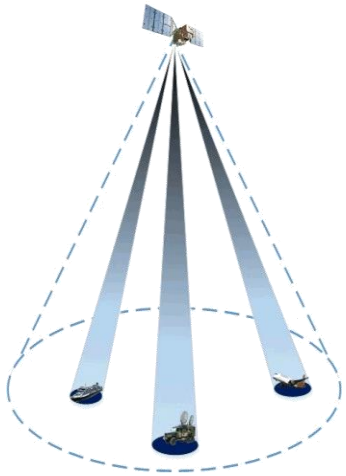


Starlink service efficiency[1]: 25.1%

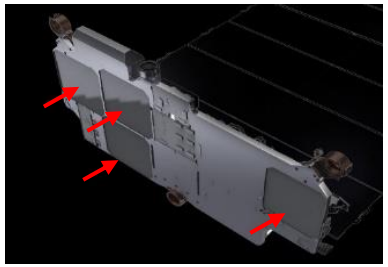
[1] I. del Portillo, B.G. Cameron, E.F. Crawley, "A technical comparison of three low earth orbit satellite constellation systems to provide global broadband," in Acta Astronautica, vol. 159, pp. 123-135, Jun. 2019.

Beam hopping can achieve on-demand coverage

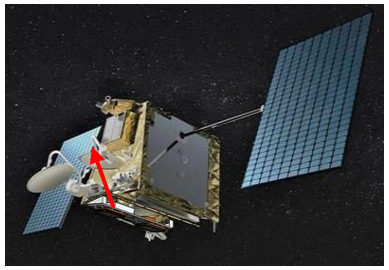
Some satellite systems with phased array antennas



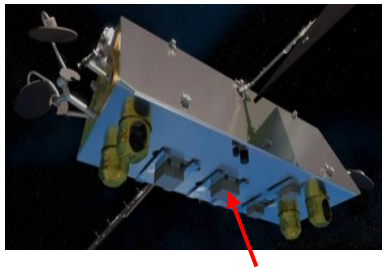
Starlink Gen2



OneWeb

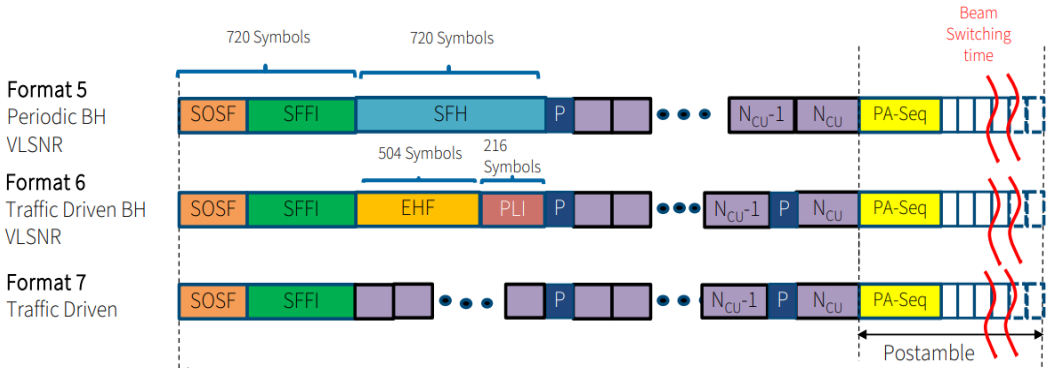


Telesat



QUANTUM

DVB standard supports BH



Three super-frame structures in DVB-S2X [1]

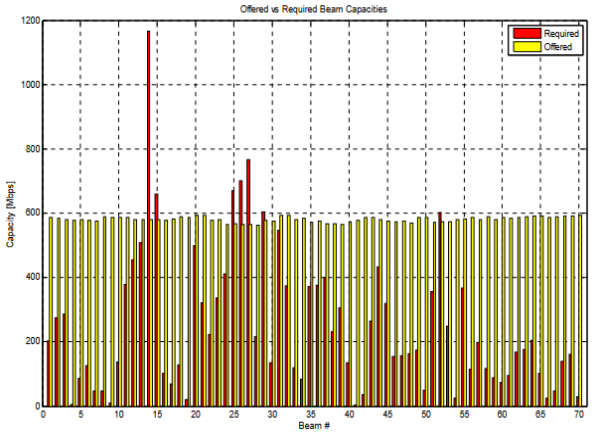
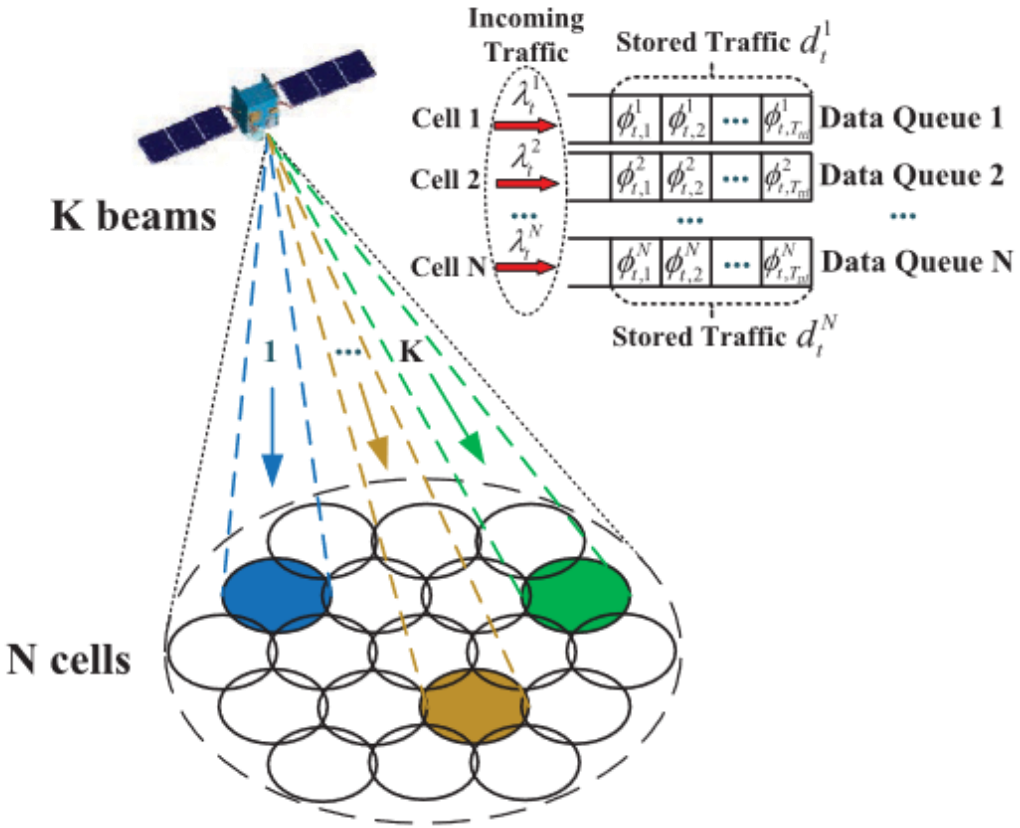


Figure C.3a: Demanded and served traffic in a conventional system

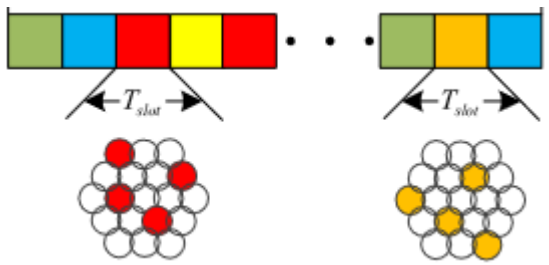
- ✓ Capacity increase by +15 %
- ✓ Better flexibility in allocating capacity to the beams with high traffic demand
- ✓ Lower DC power consumption (< 50 %)

[1] Digital Video Broadcasting (DVB); Second Generation Framing Structure, Channel Coding and Modulation Systems for Broadcasting, Interactive Servicess, News Gathering and Other Broadband Satellite Applications; Part 2: DVB-S2 Extensions (DVB-S2X), ETSI Std., Aug. 2020.

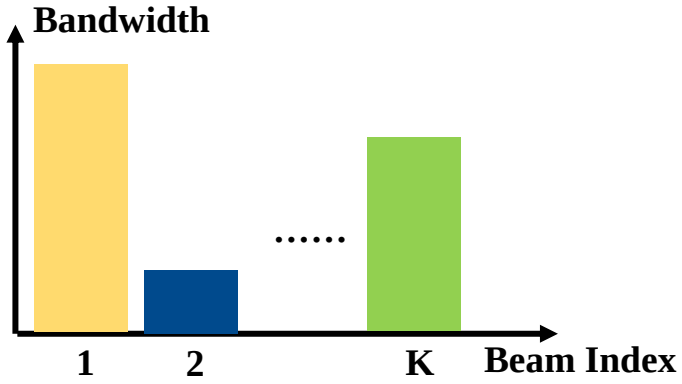
System Model: Traffic Driven BH scheduling



- **Traffic Driven BH scheduling**
- **Design BH patterns and beam bandwidth allocation slot by slot relying on real-time status of traffic queues and channel states.**



BH pattern



- **Challenges**
- **Real-time scheduling**:
  - Scheduling execution time should be less than timeslot duration (ms)
- **Multi-dimensional scheduling**:
  - Multi-beam time-space-frequency three-dimensional decision-making

Modeled as Markov decision processing (MDP)

Queue length of current timeslot

$$\Phi_t = \Phi_{t-1} + \lambda_{t-1} - Tr_{t-1}$$

Transmitted traffic of last timeslot

Queue length of last timeslot

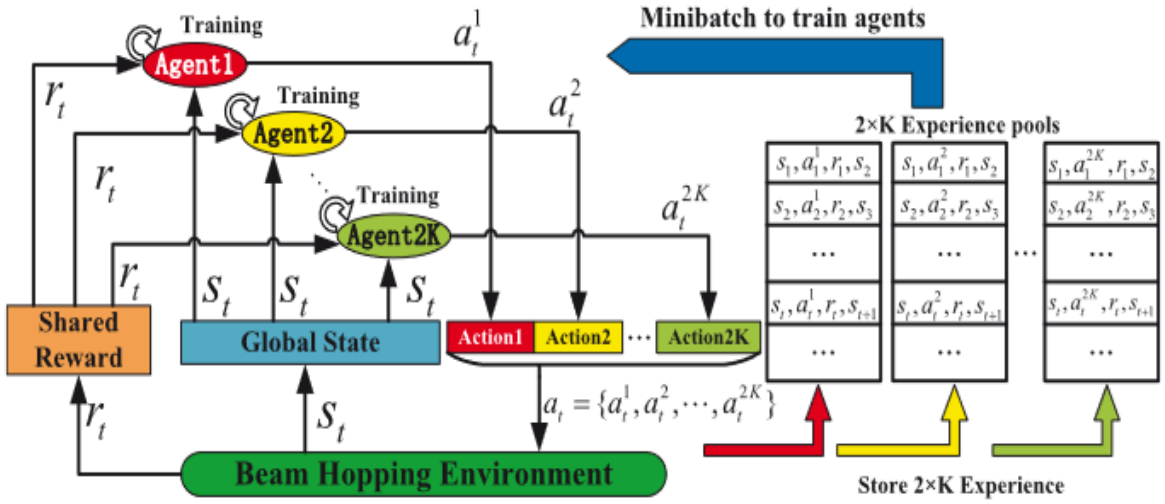
Newly arrived traffic

- State **s**: traffic queue information of different cells : ϕ_n^t
- Action **a**: beam location, beam bandwidth
- Reward **r**: defined as optimization target:

$$C = \alpha \frac{TR\_total}{TR_{max}} - (1-\alpha)\frac{Fairness}{Fairness_{max}}$$

- How to get the optimal action: multi-agent deep reinforcement learning

Multi-agent DRL BH Architecture



- ✓ **Each Beam is regarded as two types of agents**
  - ➢ Beam irradiation agent: beam location
  - ➢ Beam bandwidth agent: beam bandwidth
- ✓ **Each agent has small action space**

- ☐ **Global State:**
  - At each time slot, the system can observe the whole traffic demand as the global state and each agent can obtain this state.
- ☐ **Action Space:**
  - The BH pattern and bandwidth allocation for K beams.
- ☐ **Reward:**
  - The data throughput and delay fairness is adopted as the immediate reward.
  - All agents share a global reward which can evaluate the global performance and promote collaboration between agents.
- ☐ **DDQN Training:**
  - Since the action spaces are discrete, the well-performed Double Deep Q-Learning (DDQN) method is adopted for the agent to learn the policy.

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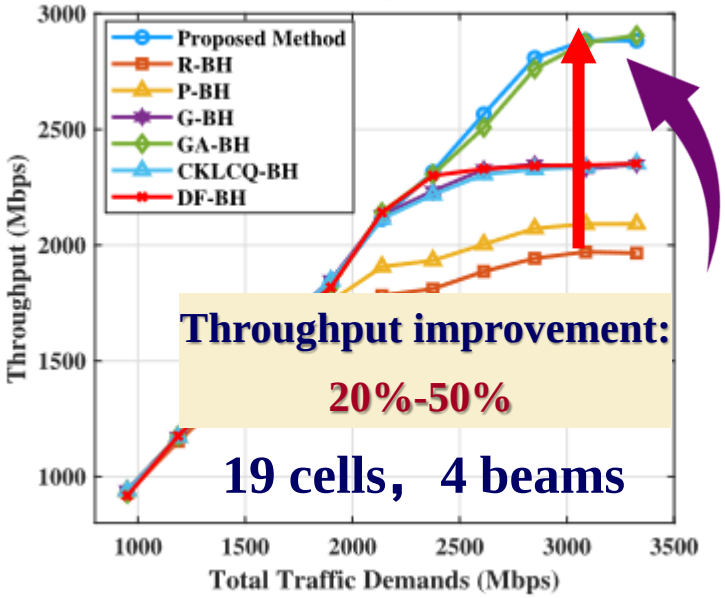
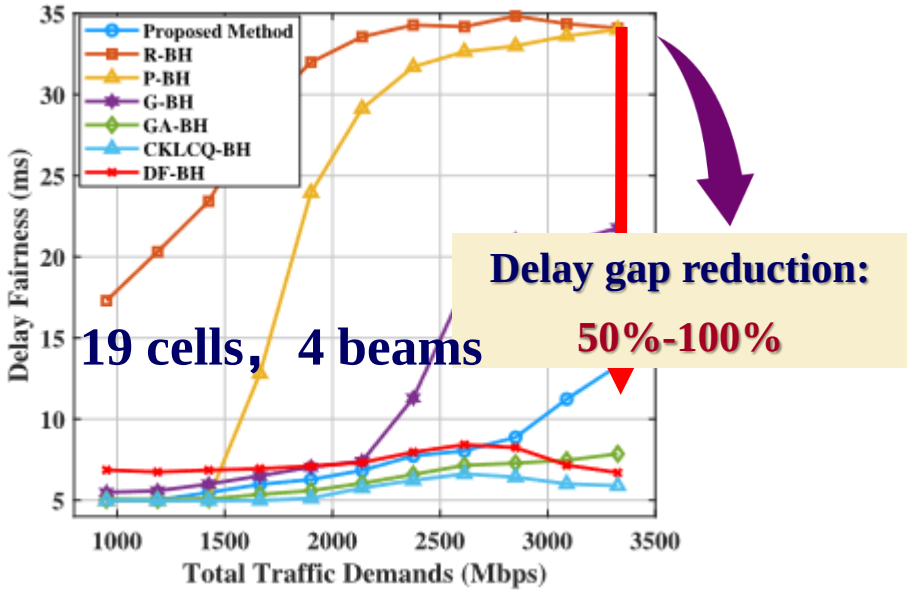
Simulation Results

Throughput



Fairness



Algorithm	Computational Complexity	Execution Time
P-BH	$O(1)$	13 us
R-BH	$O(2K)$	48 us
G-BH	$O(NT_{ttl}k + Nlog_2Nk)$	64 us
GA-BH	$O(PG(Kk^3 + (K^2 + NT_{ttl})k^2))$	3.2 s
DF-BH	$O(N($	206 us
CKLCQ-BH		148 us

Execution time is 6400 times lower

- Higher throughput than other algorithms
- Delay gap within 14ms
- Execution time is 6400 times lower than genetic algorithm

Z. Lin, et al., "Dynamic Beam Pattern and Bandwidth Allocation Based on Multi-Agent Deep Reinforcement Learning for Beam Hopping Satellite Systems," in IEEE Transactions on Vehicular Technology.