HUGHES
An EchoStar Company

Role of Satellites for Public Safety in the 5G Era

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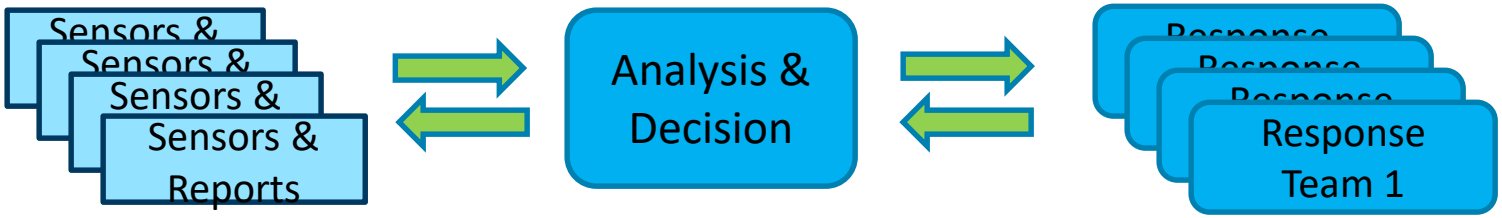
Public Safety is Very Complex

- Complexity Comes in many forms
  - Sources of real-time information come in different forms
  - Responses are provided by many agencies in all level of government (city, county, state, federal) and Non-government organizations across different jurisdictions
  - Timely and effective actions are achieved through analysis of the situation on hand and correct decision making with proper coordination among the responders
- Communications among individual networks of different capabilities and purposes are essential
  - New technologies must interoperate with legacy equipment used by different agencies while respecting the institutional responsibilities and constraints
  - Resulting in a network of heterogeneous networks



What Does 5G Offer as a Solution

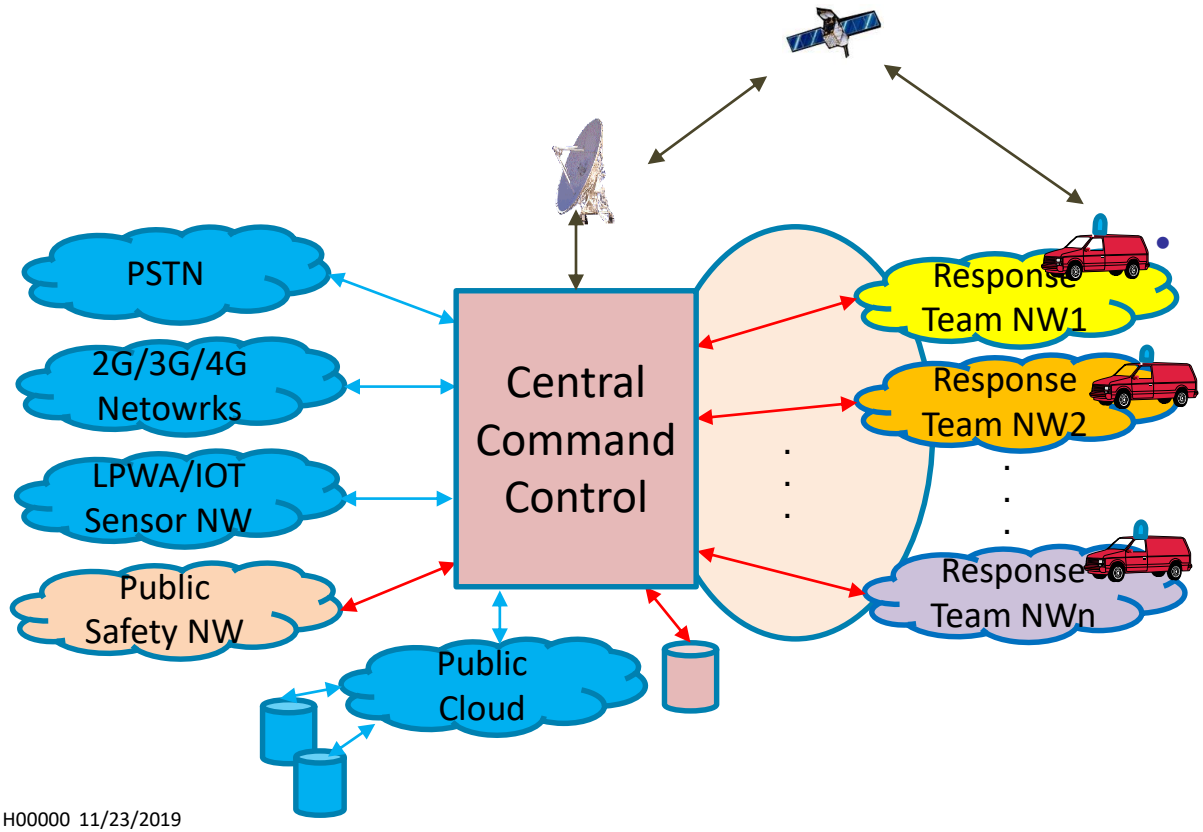
- The Vision of 5G is a Network of Networks that encompass three distinct capabilities, that serves many vertical industries
  - Enhanced Mobile Broadband (eMBB)
  - Massive Machine Type Communications (mMTC)
  - Ultra-Reliable Low Latency Communications (URLLC)
- mMTC and eMBB offer clear advantages for Public Safety but the integration of individual networks of different capabilities and applications are essential
  - Independent of 5G, attempts toward this goal have been tried, yet still work in progress
  - 5G can provide added momentum
- But, deployment of terrestrial 5G services will inevitably start with densely populated areas and spread gradually to rural community over many years,
  - Economics heavily favors high population density area
  - mmWave cells are very small

Role of Satellites in 5G Era

- Satellite communications provides wide area coverage and is the most suitable to bridge the gap
  - Ideal for rural and hard to reach terrain
- Satellites are also the top choice to restore communications quickly for disaster recovery after loss of existing infrastructure
  - Incorporating satellite communications capability as a backup or parallel path along with terrestrial wireless alternative enhances the reliability and availability
- Satellite Communications technology has progressed over the past decade or two, leading to significant increase in capability and reduction in cost
  - Very large space-deployable antennas for geosynchronous satellites (GEO), resulting in higher throughput capacity and efficiency, smaller user terminals
  - Increased availability of high capacity Reusable Launch Vehicles, reduction in satellite launch cost
  - Improved waveform design and receive signal processing for near Shannon limit performance

Satellite Capabilities in the U.S.

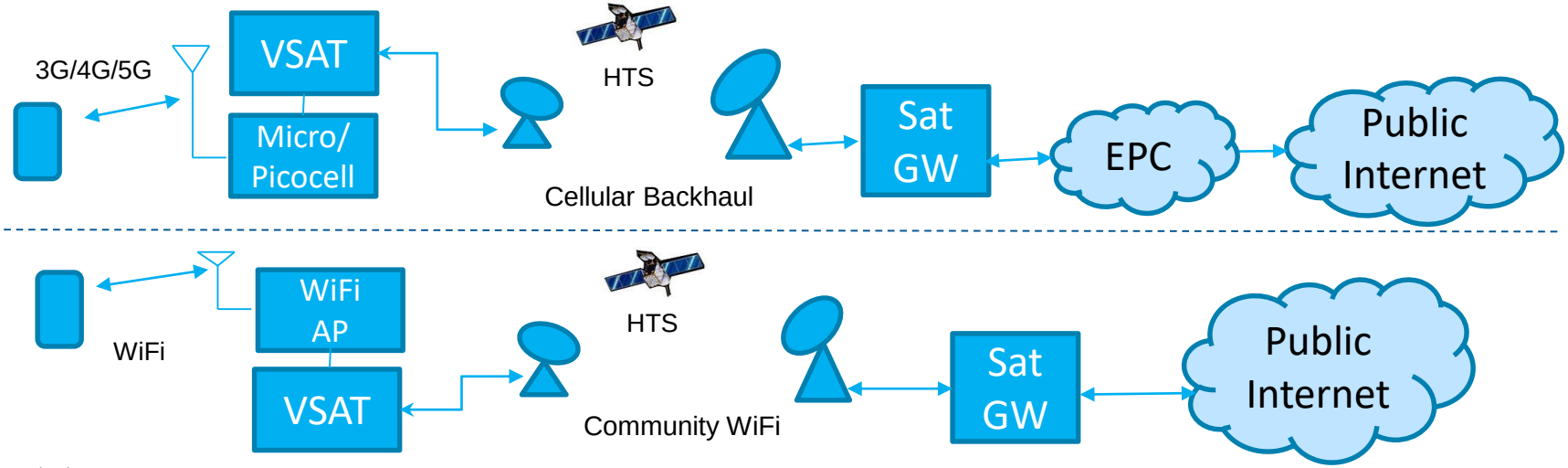
- Satellites may be added to the Response Teams as
  - Backup for existing communications
  - Only means in uncovered area



- Commercially available Ka/Ku band satellites from and to vehicle-mounted tracking antenna
  - HD video
  - Voice/Internet browsing
- Commercially available S/L band satellites to and from handhelds and portable devices
  - Low-frame rate, surveillance video
  - Voice and small data files

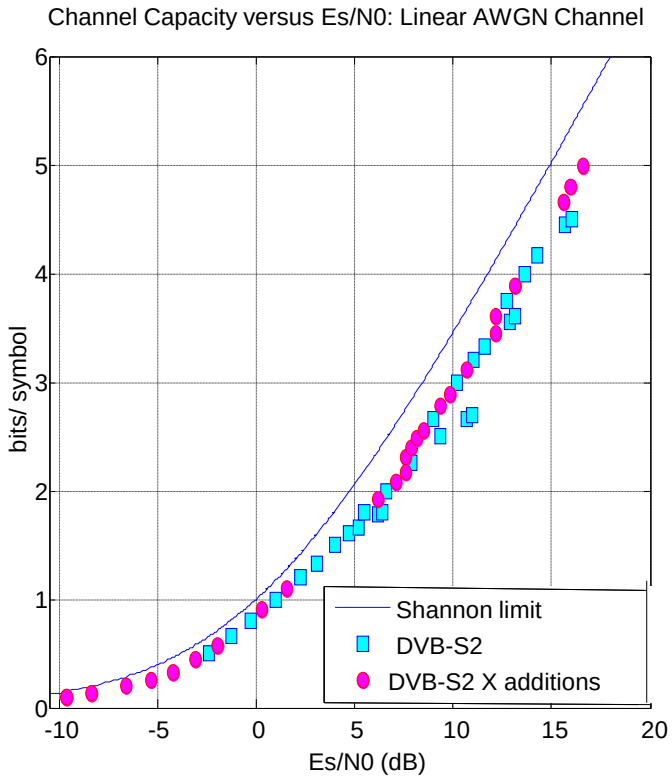
Satellite Backhaul

- VSAT in conjunction with a 3G/4G/5G cellular micro/pico-cell basestations, localized 3G/4G/5G cells can be backhauled through LEO or GEO satellites
  - Cellular backhaul accommodates both mobile and fixed users
  - Typical backhaul link can be up to 100s of Mbps downlink, 10s Mbps to ~100 Mbps for uplink when needed
- VSAT in conjunction with a WiFi AP, Community WiFi connects fixed and users with limited mobility to the outside world as well as communications between users within the community
  - Typical speeds are 100 Mbps downlink and 10+ Mbps uplink
- Both can be used on mobile platforms for rapid deployment



DVB-S2/S2X Technology Key for High Capacity and Throughput

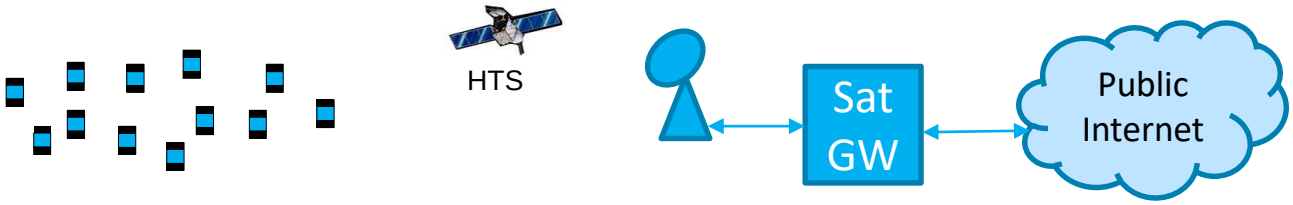
- Power efficient transmission provides near Shannon limit performance
  - Low-density parity check codes (e.g. DVB-S2 and DVB-S2X)
  - Average about 0.7dB away from Shannon capacity with 2/4/8-PSK, m-APSK modulation (m=16/32/64/128/256)
- Realized in a single-chip receiver
  - Capable of operating at multiple Gbps in a single downlink beam
  - Also applied as high throughput return link for applications such as cellular backhaul
  - VLSNR mode also support terminals at disadvantageous/degraded conditions



- Pre-distortion and other compensation techniques minimize nonlinear distortions

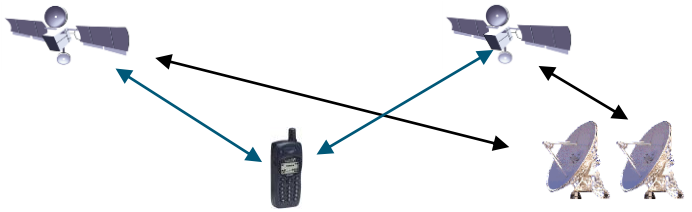
Non-Orthogonal Multiple Access

- Non-Orthogonal Multiple Access (NOMA) techniques have been proposed for 5G wireless
  - NOMA allows successful transmission of many short messages from different users at the same frequency and the same time
  - We have been operating a version of NOMA in our commercial VSAT network in the North America since 2017 as a replacement for Slotted-Aloha RACH for high-priority traffic in the return link
  - The Asynchronous version is about 10 times as efficient in capacity and 10 times as reliable in burst error rate as the Slotted-Aloha technique
  - Further spreading may be applied to ACMA to reduce out-of-band emission for ultra small terminals as needed
- With NOMA Techniques dedicated return channels are no longer needed. Terminals can transmit whenever they have data to send
  - Replacing Aloha or S-Aloha random access
  - To play a major role for satellite return-link access and satellite IOT



5G NR Technologies Applied for Satellite Networks

- When a large LEO constellation is deployed, a user terminal will have access to more than one satellites simultaneously. 5G NR Multiple-Input Multiple-Output (MIMO) and diversity combining technologies may be adopted to enhance
  - Speed of data transmission
  - Power and bandwidth efficiency
  - Reliability



in the same way MIMO and diversity enhance terrestrial networks

- Dual mode terrestrial/satellite user terminals supporting direct access to the satellites without significant compromises in speed and capability of the 5G services when terrestrial service is not available
- Tightly coupled networks among command centers, response teams, and sensor networks with significantly reduced latency and improved reliability

Satellite Integration in 5G Standard

- 3GPP studies on non-terrestrial network (NTN) for 5G system have started in March 2017, thanks to a joint work between cellular and satellite stakeholders.
  - Rel. 15 studied the potential impact on NR when introducing NTN
  - Rel. 16 studied the potential solutions for introducing NTN with minimum impact on NR
  - Rel. 17 will start in early 2020 for the related normative phase and additional study items for Rel 18.
- The goals of standardization: To improve service quality and provide seamless connectivity between satellite and terrestrial networks
  - reliability and availability for critical communications needs
  - essential for public safety and disaster relief
- NTN integration into 5G ecosystem enables direct connectivity
  - broadening services to unserved or underserved areas
  - extending and complementing the performance terrestrial network performance