Cellular in Aviation

- Opportunities
- Challenges
- GUTMA “Aerial Connectivity” WG

Presented to: ATIEC 2019

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Date: Sept 23, 2019

Part I : Technical Background

Some definitions

- **UE = user equipment = the modem on the mobile side (a cell phone, a UAV, etc.)**
- **BTS, eNB, gNB = the base station side (cell tower) serving a cell**
  - Often sectorized, e.g. 3 sector of 120°
- **Downlink = BTS->UE; Uplink = UE->BTS**
  - This is unfortunate choice of terms where UAVs are concerned, because it is backwards.
  - But it is very embedded into cellular language, and will not change for our convenience.
- **3GPP = the one, unambiguous standards body for cellular industry**
  - (in contrast to aviation world)

Opportunity: cellular in aviation

- **FAA/FCC (and analogous groups worldwide) are working to define C2 Options for UTM:**
  - **Unlicensed:** inherently unpredictable/unmanaged, making safety challenging
  - **Dedicated aviation spectrum:** could be safe and reliable, but…
    - Spectrum scarce
    - Would require expensive new infrastructure and radios, greatly limiting UTM
    - Many missions require a payload modem, so would need another modem anyway
  - **Commercially licensed spectrum:** very convenient and cost-effective:
    - ***But is it sufficiently safe/reliable?***

Advantages

- **Modems cheap and highly efficient, versus bespoke systems**
- **High amount of spectrum; inherent redundancy of multi-band devices**
- **Broad deployment worldwide, especially in most valuable airspaces**
- **Aerial/LOS channel predictable and surprisingly robust (even with downtilt)**
- **Extensive features (especially in 5G) for quasi-dedicated services on common infrastructure**
- **Robust identity & security, sufficient for you to make daily financial transactions**
- **Handover to other systems can be done ad-hoc or pre-planned**
- **More than just a C2 system. Also:**
  - Redundant navigation system
  - Dense network of “tower, power and backhaul”, with connected edge compute, that can be leveraged for any purpose

Commonly expressed concerns

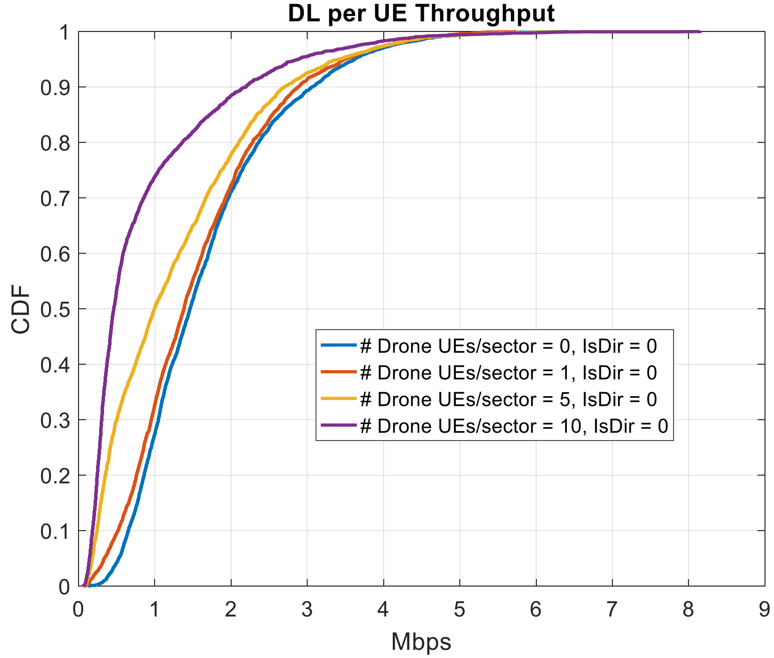
- **“What about downtilted antennas? Can I really rely on an artifact that might disappear with a minor adjustment?”**
- **“I have a phone, and my call drops sometimes.”**
- **“If mission-critical traffic is mixed with commercial traffic, how do I know there will be capacity when needed?”**
- **“How can it serve a mission-critical role if there is not coverage everywhere?”**
- **“Can a commercial business manage a mission-critical network? Aren’t their priorities different?”**
- **“Can’t cellular be jammed?”**

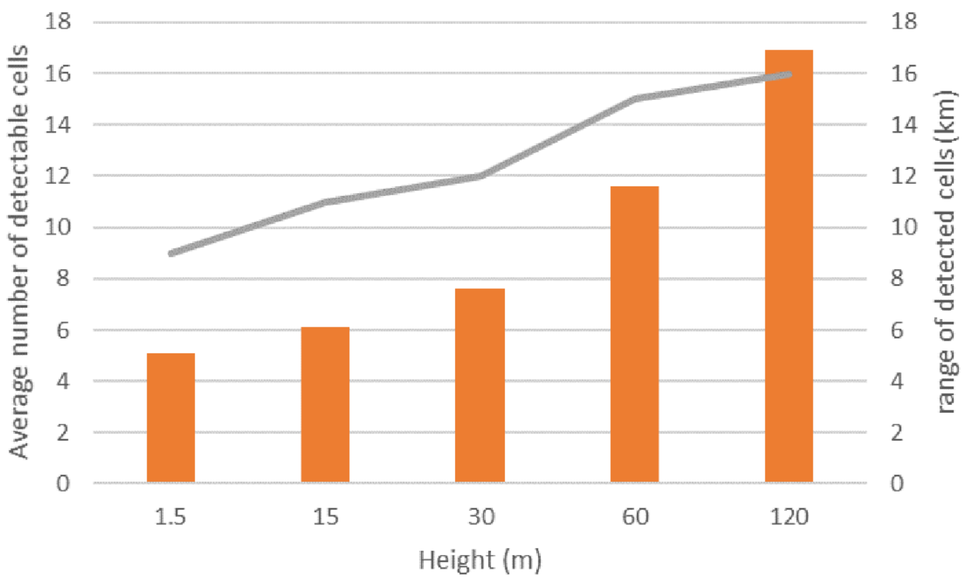
Some brief responses

- **LOS channel is surprisingly good even with downtilt**
  - And uptilt networks do exist (e.g. Smartsky, EAN)
- **Aerial channel is also more predictable than terrestrial channel**
  - This is significant especially when path is planned in advance
- **"Network slicing" and QoS allow a range of approaches from generic/shared service to quasi-dedicated behavior**
- **SON (self-organizing network) and self-healing can provide operational reliability**
- **Handover to non-cellular system can take place if and when needed (with foreknowledge)**
- **Any spectrum can be jammed; cellular modems are inherently redundant, and wideband modulation inherently robust**
- **There is ample precedent for gov't use of commercial networks. Variety of approaches and mechanisms for monetization, liability, etc.**
- **UTM and C2 system, if properly coordinated, can help each other immensely**
  - In the end, coordinated UTM/C2 can likely be very predictable/reliable

(See ICARO-EU video at: **https://www.youtube.com/watch?v=4LdnbmCsRWw)**

Issue 1: Interference

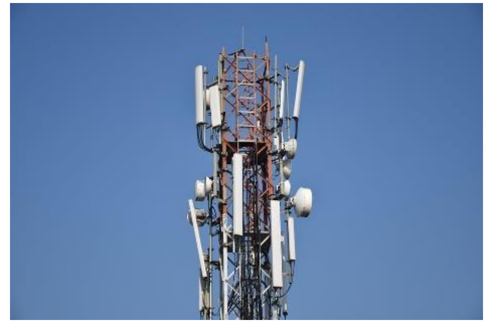


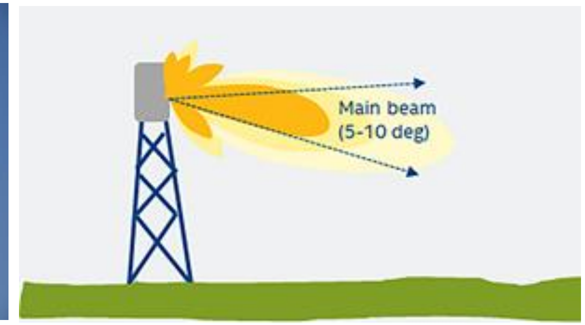


- Aerial/LOS path loss exponent $1/r^2$. Terrestrial is $\sim 1/r^4$ to $1/r^5$
- With more aerial UE, interference rises and throughput drops
- This happens on both Uplink (i.e. reverse link, UE->eNB) and Downlink (i.e. forward link, eNB->UE)
- Affects both UAVs and terrestrial users (i.e. main source of $$$)

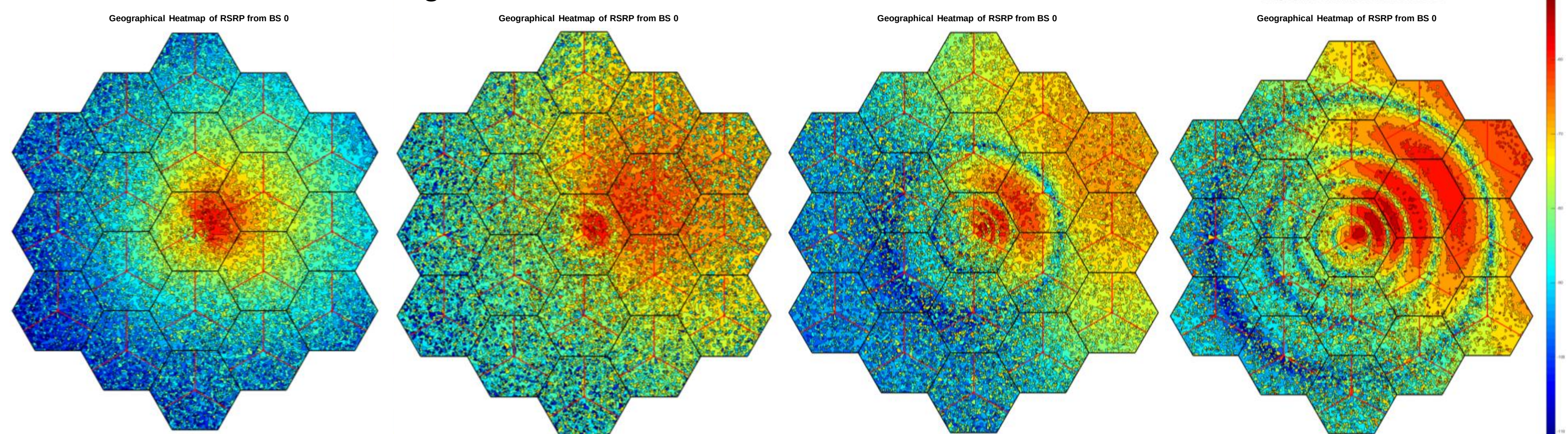
Issue 2: "mosaic" coverage

- **Main lobe downtilted**
  - In the air, the UE operates largely on side lobes





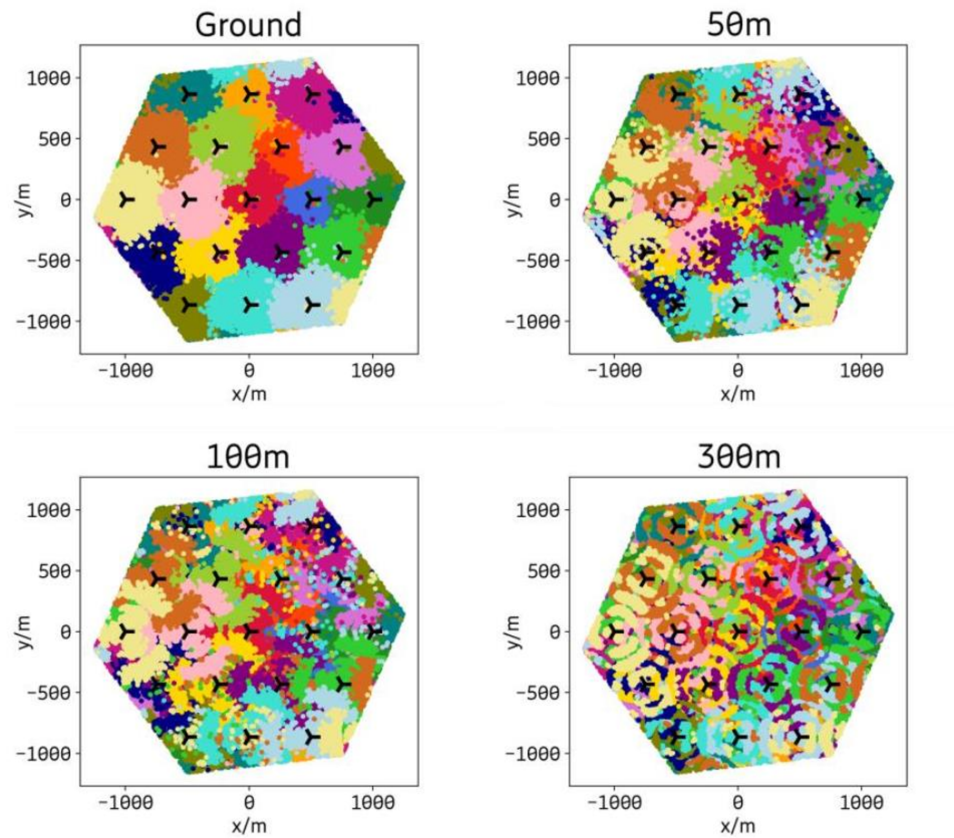
- **RSRP from one sector at 0m, 50m, 100m, 300m from simulation, downtilt 10°**
  - Red = higher RSRP (reference signal received power)
    - At 0m, coverage matches sector boundaries well



- Source: Intel Simulations

Complexity of coverage picture

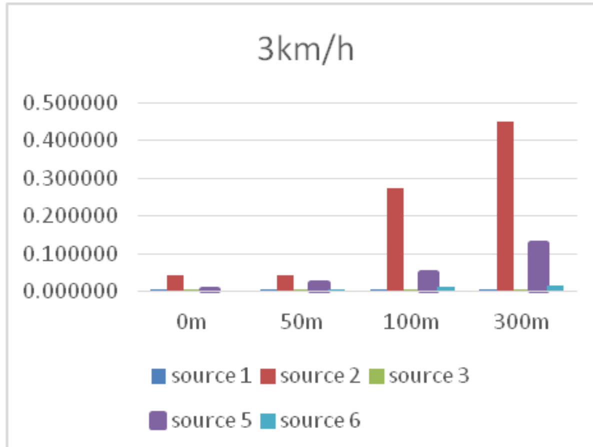
- Color codes the eNb with best connection to UE at various heights
- At altitude, the picture is complex
- This is challenging for handover algorithms design for terrestrial channel

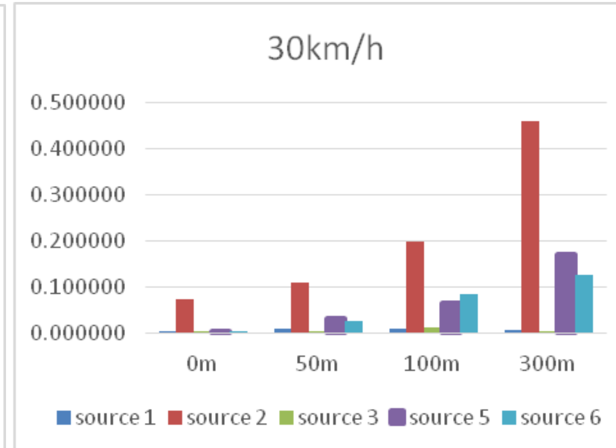


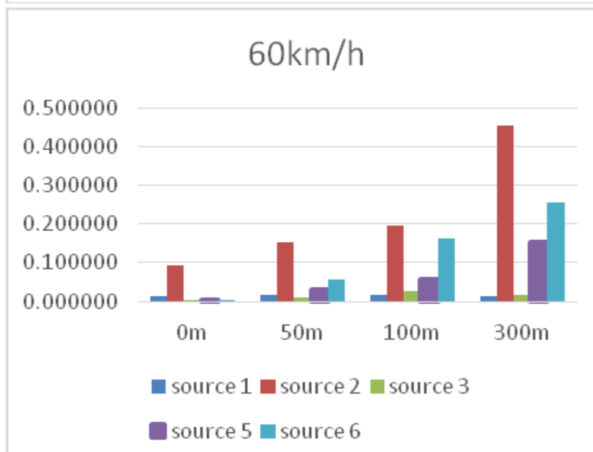
- Source: Figure 5 from “Mobile Networks Connected Drones: Field Trials, Simulations, and Design Insights”, Xingqin Lin et al., Ericsson and Cornell University, https://arxiv.org/abs/1801.10508

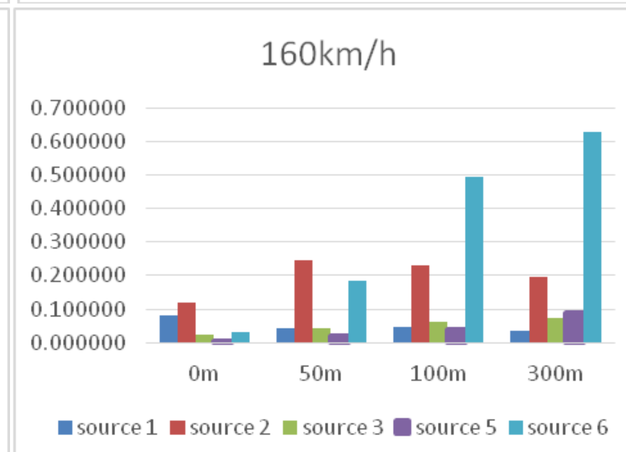
Dropped handovers due to RLF for aerial vehicles (omni antenna)

- Various simulation contributions from 3gpp contributions [TR36.777, sec J.2.4]
- Independent contributors arrived at different numbers, but generally see more dropped HO due to RLF with altitude
- This has been a topic of some controversy. The standard is not strictly prescriptive, and HO algorithms designed for terrestrial may vary in aerial performance



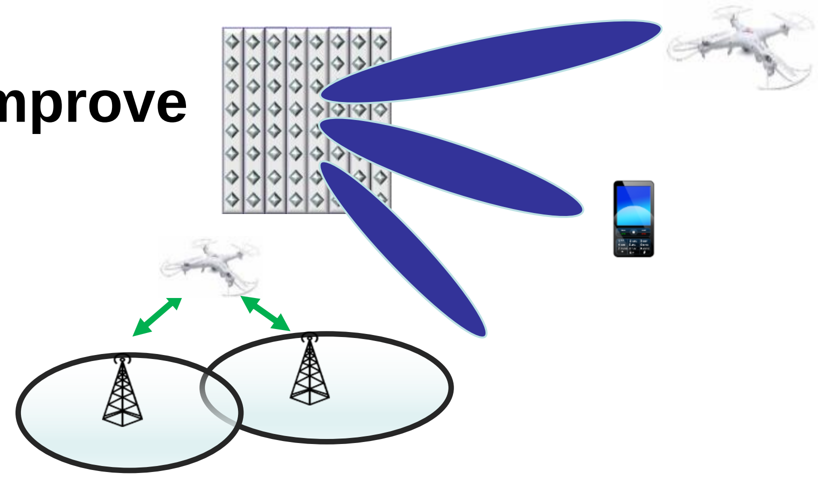






Solutions

- **There are many opportunities to improve**
  - UE improvements
  - Network improvement
  - Joint UE & Network improvements
  - Cellular and UTM integration



- **But what's already deployed is more than sufficient to start**
  - There is no "chicken and egg" problem (i.e. expensive optimizations needed to serve business, but business needed to justify expensive optimization)
- **The hurdles are primarily regulatory and industry coordination, not technical**

What is integrated "UTM/C2"

- **The UTM system and C2 system can help each other immensely (if they talk)**

- **C2 system -> UTM system**
  - Coverage mapping, including handover points to non-3gpp system
  - Vehicle control such as facing direction, or speed during handover
  - C2 recovery procedure in off-nominal condition
  - Connected status leverages for UTM purpose
  - Monitoring compliance (e.g. network of Remote ID compliance sentinels)

- *UTM system: "Where do you have coverage?"*

– **UTM system->C2 system**
  - Flight-plan based-beamforming, handover, power control
  - Flight-plan-based dynamic network configuration
  - Closing the loop on C2 mapping (SFM->point cloud->updated RF map)

- *C2 system: "Where do you need coverage?"*

Positioning

- **Performance in the air of OTDOA can be quite a bit better than on the ground**
- **"Redundancy" of OTDOA is questionable because base station itself uses GPS as a time source. But looser methods that do not require tight timing are truly redundant.**
  - Research is ongoing into self-synchronizing networks for true redundancy

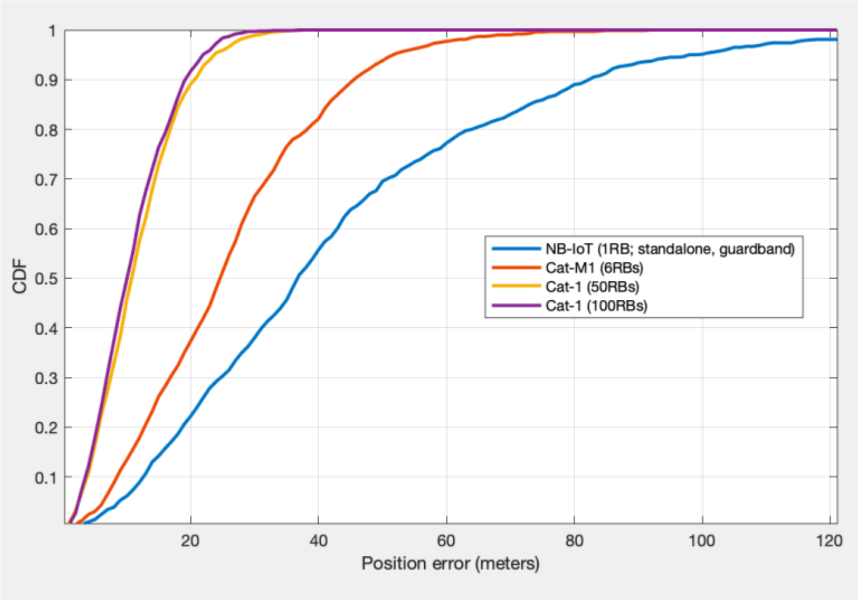
A summary of the 3GPP releases, from a **positioning** perspective, is as follows:

2010		*2015*	*2017*	*2019*	*2020*
Release 9		**Release 13**	**Release 14**	**Release 15**	**Release 16**
OTDOA Positioning Reference Signals (PRS) introduced Enhanced Cell ID (eCID) introduced	......	Introduction of LTE-M and NB-IoT Indoor positioning study item (TR 37.857)	LTE-M and NB-IoT positioning support Positioning enhancements: High resolution RSTD, CRS+PRS, Multipath RSTD	5G phase 1 Ongoing LTE-M and NB-IoT enhancements Positioning enhancements: GNSS-RTK, IMU, assistance data broadcast	5G phase 2 Ongoing LTE-M and NB-IoT enhancements Positioning enhancements: 5G NR Positioning, UE-based OTDOA, Autonomous vehicles

- Source: Steve Caliguri, Acorn Technologies, https://gutma.org/portland-2019/presentations/
  - Full presentation is online and includes much more explanation

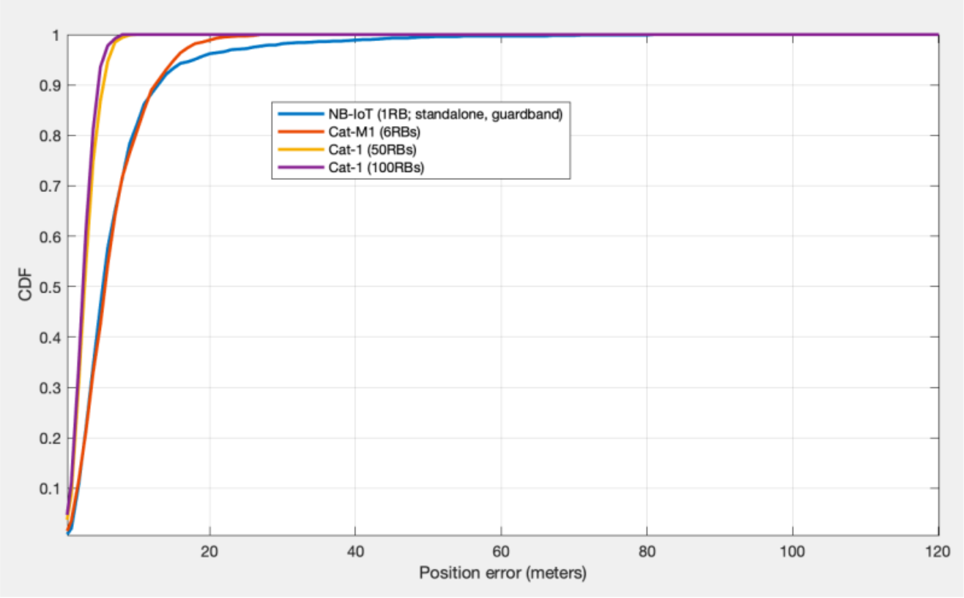
Example hellaLOC from Acorn

Terrestrial Example



Acorn Technologies

Aerial Example



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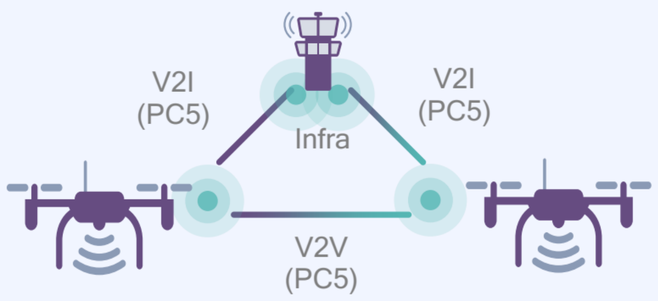
Cellular V2X

Direct communications

V2V, **V2I** on "PC5" Sidelink Interface
not via the cellular network infrastructure

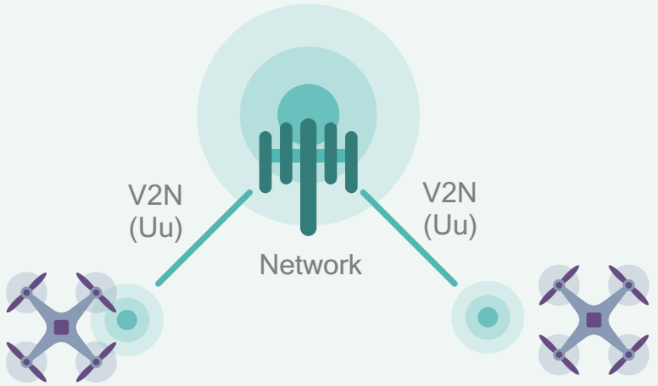
PC5 interface



Network communications

V2N on "Uu" interface operates in traditional mobile broadband licensed spectrum

Uu interface



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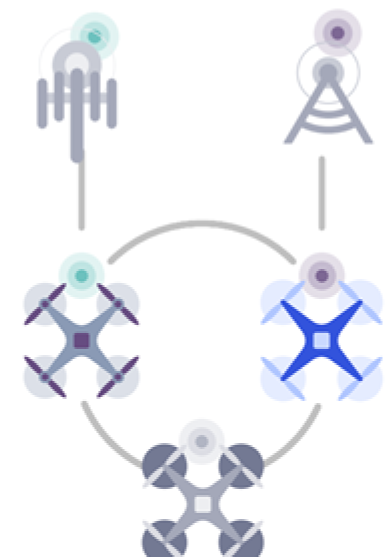
C-V2X is designed to work without network assistance

V2V/V2I/V2P direct communications enables low latency applications

USIM-less operation	C-V2X direct communications doesn't require USIM
Autonomous resource selection	Distributed scheduling, where the vehicle selects resources from resource pools without network assistance
Network coordinated resource mgmt	3GPP also defines a mode, where eNodeB helps coordinate C-V2X Direct Communication
GNSS time synchronization	Besides positioning, C-V2X also uses GNSS for time synchronization without relying on cellular networks



Direct communications
(via PC5 interface)

- Source: Stefano Faccin, QUACOMM, https://gutma.org/portland-2019/presentations/
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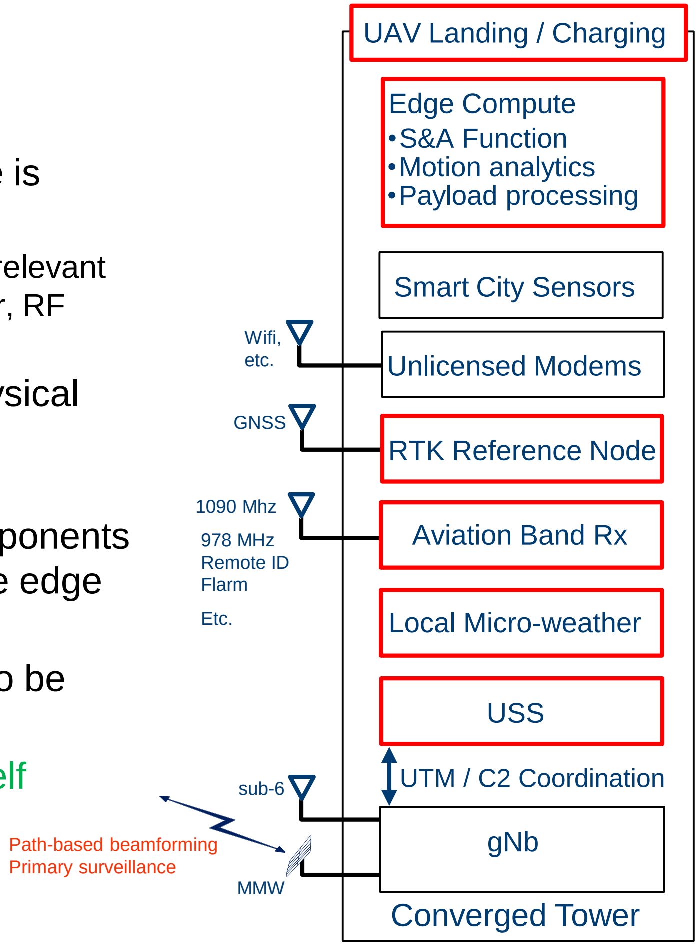
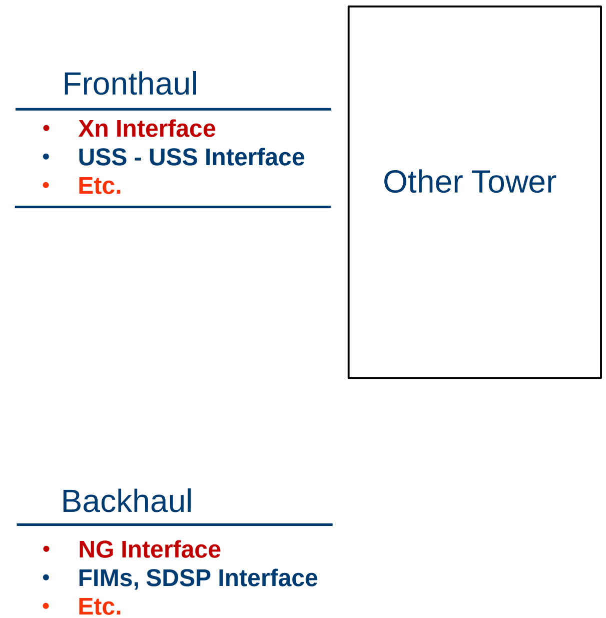
Converged tower conceptual diagram (*)

- 5G networks are also a “distributed connected computing” network
- Aviation/UTM by nature is localized
  - Objects and data are relevant locally (traffic, weather, RF environment)
- UTM needs distributed physical sites with tower, power, backhaul, fronthaul
- UTM has software components that need to be near the edge for multiple reasons
- UTM/USS also needs to be near its C2 network

✓ The 4G/5G network itself meets all these criteria



- COMMON THEME IN INDUSTRY:
- The need to distribute applications along multiple processors, from vehicle to deep cloud



(*) aviation items in orange; each is expanded in Backup

Part II: Non-technical issues

Aviation/Defense vs. Consumer/Commercial

- **The commercial/consumer and aviation/defense communities have not coordinated well, having mostly disjoint standards bodies, trade shows, industry organizations, and conferences. As a result:**
  - It is difficult for aviation stakeholders to know with confidence what options exist in commercial networks, and how they might mesh with other options
  - It is difficult for commercial/consumer communication providers to understand what aviation wants and needs from them
  - There is poor prospect for inter-system interoperability between aviation-oriented and commercial-oriented networks
  - Research funding typically not focused on consumer/commercial companies, even when the topic is using their technology
- **This is "easy to observe, hard to fix"**

Aviation/Defense vs. Consumer/Commercial (2)

- **RTCA: "cellular folks can come make contribution here"**
- **3gpp: "aviation folks can come make contribution here"**

- **Aviation expert: "I'll dabble in cellular and wisely decide how to use it"**
- **Cellular expert: "I'll dabble in aviation and then wisely decide what services are needed"**
  - Neither is realistic
  - Each field is massively deep
  - Two-way dialogue is needed

- **"C2 is intermittent anyway, does it matter?"**

Some examples

- **Release 15 flight declaration:**
  - 3gpp is using a trajectory-only flight declaration
    - Simply a list of 3D waypoints & times
  - ASTM, NASA, others use a set of 4D volumes, with no indication of whether the vehicle can be presumed to follow a straight line trajectory or not
  - These declarations are not “translatable”; they simply don’t contain the same information
  - If eNb/gNb implement beamforming and handover based on 3gpp-type flight declaration, and USS uses ASTM.F38-type flight declaration, we have created an avoidable problem
- **Release 15 architecture mismatch with UTM:**
  - There is no clear rationale for why the eNB should asking the UE, over the air, for flight plan information
  - This would be controlled from the USS; it could come to eNb over the backhaul
  - There is no reason to go over the air twice in, for example, the ASTM architecture

Some examples (2)

- **Some examples from 3GPP Release 16 TS22.125**
  - *The 3GPP system shall support a direct UAV to UAV local broadcast communication transport service at relative speeds of up to 320kmph*
  - *The 3GPP system shall support a direct UAV to UAV local broadcast communication transport service with variable message payloads of 50-1500 bytes, not including security-related message component(s)*
  - *The 3GPP system shall support a direct UAV to UAV local broadcast communication transport service which can support the maintenance of UAV to UAV separation. UAVs are considered separated if they are at a horizontal distance of at least 50m or vertical distance of [30]m or both(*)*
  - *The 3GPP system shall support a direct UAV to UAV local broadcast communication transport service which supports a range of up to 600m*
  - *The 3GPP system shall support a direct UAV to UAV local broadcast communication transport service which can transmit messages at a frequency of at least 10 messages per second*
- **Red items above are aviation statements that should be based on input from aviation stakeholders**

So what would be more productive?

- **Common set of KPI (Key Performance Indicators)**
  - Level 0 service, Level 1 service, etc.
  - Agreed between 3GPP and aviation; then each can focus on its area of expertise
- **M2M exchange between C2 and UTM**
- **Various studies such as:**
  - Aerial CV2X for Remote ID and DAA
  - Higher altitude studies
  - MMW for C2, location, and sensing
  - Interfacing to ATN/IPS, seamless interop with other aviation systems
  - Long list of aerial performance improvements
  - Edge compute for aviation (maximizing agility of UTM, for ATM/UTM integration)
  - LDACS based on COTS LTE equipment
  - Truly redundant positioning
  - …complete list beyond the scope here

- **GUTMA's new WG "Aerial Connectivity" proposes to fill standards gaps arising from this lack of connection between the communities**
  - Not "yet another" requirements generator, collator, etc.
  - Focus is on corrective SDO contributions to bring into reality the opportunities

What is GUTMA?

The Global UTM Association (GUTMA) is a non-profit consortium of worldwide Unmanned Aircraft Systems Traffic Management (UTM) stakeholders.

Its purpose is to foster the safe, secure and efficient integration of drones in national airspace systems. Its mission is to support and accelerate the transparent implementation of globally interoperable UTM systems.

GUTMA members collaborate remotely.

Association

Based in Lausanne, Switzerland
Representing 70+ organizations
Present in 25+ countries worldwide

We unite

- Air navigation service providers
- UAS operators
- UAS manufacturers
- UTM data & software providers
- Infrastructure providers
- Insurance & consulting corporations
- Regulatory bodies
- Academic experts

www.gutma.org