Infrastructure-less Mobile Satellite Communication in Ka-Band for Disaster Relief Operations

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Outline

- Introduction and Motivation
- Disaster relief scenarios
- Technical solution candidates
  - Available on the market
  - Hub-centric and hub-less architectures
- Antenna and link type characteristics
- Technical challenges
  - The meshed connectivity challenge
  - The satellite-on-the-move challenge
- Economical challenges, way forward and conclusions
Introduction

- Our communication world is a connected world
- State-of-the-Art communication systems are
  - Wireless, short range (cellular 3G/4G/WiFi)
  - Wireless, regional (satellite spot-beams)
  - Wired, local (POTS, cable and xDSL)
- Complemented by broadcast systems through
  - terrestrial, cable, and satellite distribution
- What’s common to all these communication systems?
  - Highly complex and mostly managed
  - Rely on working infrastructure
Introduction

- Provision of ubiquitous communication infrastructure is key for our society
  - And an extremely high effort is spent to enable this
- All communication infrastructure has some very basic requirements
  - (mains) power, interconnection, management, access to content
- And it works really very well 24/7 even in severe conditions
  - Weather conditions

- Resilience and quick recovery after blackouts / power surges

- So, everything fine?
Introduction

- No … from the point-of-view of our goal to provision ubiquitous communication
- Can you imagine how long it takes to re-establish communication?

Earthquake
Haiti 2010

Earthquake / Tsunami
Japan 2011
Introduction

Without being disrespectful, different types of disasters could be:

- Earthquakes
- Volcanic eruptions
- Cyclones, tsunamis, storm floods
- Avalanches, landslides
- Wide-area firestorms

Quick establishing of communication is key for the disaster relief
Motivation

- After such disaster - which communication is to be re-established?
- On short term (within 0 - 24 hrs after disaster event)
  - Communication needs of search- and rescue-teams
  - **Early response: Infrastructure-less communication required**
- On medium term (within a few days)
  - Emergency communication for the population
  - **Alternative infrastructure required**
- On long term (within a few months)
  - Regular communication for the population
  - Fiber and copper cables, backbones, service centers reinstalled
  - **Regular ground infrastructure rebuilt**
Motivation

- Short term (0 – 24 hrs)
  - Collect information
  - Share information
  - Coordinate work
- Medium term (days)
  - Larger teams
  - More management centers
  - Emergency communication
- Long term (months)
Motivation

- **Short term (0 – 24 hrs)**
  - Collect information
  - Share information
  - Coordinate work

- **Medium term (days)**
  - Larger teams
  - More management centers
  - Emergency communication

- **Long term (months)**
  - Dependency from ground infrastructure
  - Number of users
  - Amount of traffic
  - Importance of satellite solutions
Motivation

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Motivation

- Ideally, the short- and medium-term solutions should be identical
  - A smooth transition between the search- and rescue- communication towards emergency communication reestablishing can be achieved

- Advantages for a single solution are:
  - Not a plurality of equipment required
  - The transition runs at the required pace, dependent on the severity and expansion of the disaster
  - Different priorities could be assigned by the disaster management
Early response

- Rescuers are informed about status and status updates
  - Upon arrival, during movement, during rescue operations
- Management center is informed about the scene
  - While the rescuer teams are working
- Required communication needs contain (incomplete list)
  - Video streams or video captures from the scene
  - Audio and video phone calls and conferences
  - Geographical map distribution and updates
  - Data exchange and internet access
Early response

- Quick installation of a local disaster management center
- Several small local coordination centers
  - Acting as local access points
- Base stations for cellular communication of rescuer teams
  - TETRA
  - 3G / 4G based
- Is all this feasible with today's technologies?
Alternative infrastructure

- Rebuilding of emergency communication for the population
- Requirement to bring back mobile communication into operation
  - eNB backhauling through satellite (non-GEO systems?)
- Rebuilding of (possibly remote or mobile) core network
  - In an area outside the disaster area, with mains power
- Installation of a lower number of (mobile) eNBs / base stations
  - Within the disaster area, where mains power is still unavailable
  - Installed on trucks with power generators and satellite backhauling
- Are today's cellular technologies ready for such usage?
Summary of Introduction

- The potential role of a satellite-based system for disaster relief
  - Completely stand-alone, self-organizing communication systems
  - Backhauling of mobile eNBs with remote core network
  - Terminals acting as gateway for small Wifi cells
- Application scenarios are “fixed” and “mobile” operation
  - Fixed: eNBs, Wifi access points, local disaster management center
  - Mobile: Trucks, helicopters, rescuers moving in/out/around
- Short and medium term solutions the are our focus
Technical solution candidates available on the market

- Let’s have a look, which technologies, solutions and systems are already available on the market
- Hub-centric systems (L-Band, C-Band, Ku/Ka-Band)
  - Latency issue, especially for GEO systems?
  - Direct on-board routing / through gateway?
  - Support for mobility?
  - Support for very-low SNR (small antennas)?
- Proprietary solutions?
- Hub-less systems?
Technical solution candidates available on the market

- General-purpose systems – world-wide availability (e.g. L-Band)
  - Iridium
  - Inmarsat 4
  - Thuraya
- Systems with dedicated frequency assignment and on-request availability
  - Emergency.lu (C-Band)
- Systems with shared (*) frequency assignment and world-wide availability
  - GlobalXpress (Ka-Band)
  - O3B (Ka-Band)
- And for sure many others…
- (*) shared = frequency is reused on other orbital positions
System Architecture – Hub-Centric

System architecture - Hub-centric system

- Gateway
- Disaster management center
- On-site team(s)
- On-site access point(s) (3G/WiFi)
- On-site management center
System Architecture – Hub-Centric

- Are Ka-Band systems like GlobalXpress suitable?
- Attractive coverage and cost/bit
- Interfacing to a hub-centric system
  - “Digital” (through gateway)
  - “Analog” (through satellite)
- Main missing elements are
  - Low latency (single-hop)
  - Support for different terminal types
  - Meshed connectivity
- Importance of missing elements?
Let’s broaden our view – which other concepts exist?

- Hub-less and fully meshed system
  - Today: mainly proof-of-concept
  - In the future: state-of-the-art?

Specificities of a fully meshed system
- One-to-one comm.
- One-to-many comm.
- Many-to-many comm.

Specificities of a hub-less system
- No dedicated master station
- Decentralized resource allocation?
Technical Challenges

- Self-organization of communication system
  - Few external parameters could be provided, like
    - Satellite orbital position
    - Satellite transponder frequency / polarization
- No centralized hub-station / dedicated satellite gateway
  - Management of resources among communication partners
  - Traffic priorities to be managed
- No large uplink antenna available
  - Decentralized uplink from different terminals crucial to properly drive satellite input feeds
Technical Challenges

- Applications requiring low-latency
  - Dual-hop less suitable, single-hop preferred
- Antenna tracking in mobile environment
- Support of antennas with different G/T and different directivity
- Modulation and channel coding suitable for mobile environment

A possible solution for the technical challenges we face in disaster relief is a self-organizing, fully meshed communication system, suitable for fixed and mobile communication conditions, and preferably through satellite.
Hub station based system (e.g. DVB-S2 / DVB-RCS)
- Designed for connectivity of satellite terminals to terrestrial networks
- Direct communication between satellite terminals is the exception

Direct connection between satellite terminals, either as
- One uplink terminal per carrier frequency active
- Uplink terminal with high UL-EIRP required (large dish)

Or
- Several subcarriers per transponder (FDMA)
- Bandwidth per subcarrier can be assigned according to UL-EIRP
## System Architectures - Characteristics

<table>
<thead>
<tr>
<th></th>
<th><strong>Hub-centric</strong></th>
<th><strong>Hub-less multiple carrier</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Delay Sat-UE to Sat-UE</td>
<td>Double hop (&gt;500ms)</td>
<td>Single hop (&gt;250ms)</td>
</tr>
<tr>
<td>(if GEO)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Satellite EIRP utilisation</td>
<td>Almost perfect</td>
<td>back-off in multi carrier</td>
</tr>
<tr>
<td></td>
<td>Low backoff</td>
<td>operation</td>
</tr>
<tr>
<td>Support of many UE</td>
<td>Yes</td>
<td>Limited to number of carriers</td>
</tr>
<tr>
<td>Support of mobility</td>
<td>DVB-RCS2 under development</td>
<td>Proprietary systems</td>
</tr>
<tr>
<td>Flexibility (e.g. dynamic</td>
<td>High</td>
<td>Limited, only carrier</td>
</tr>
<tr>
<td>assignment of resource)</td>
<td></td>
<td>bandwidth reconfiguration</td>
</tr>
<tr>
<td>Routing</td>
<td>Hub station</td>
<td>“Meshed” (if UL/DL same spot)</td>
</tr>
</tbody>
</table>

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Disaster Relief – usage scenario

- High flexibility of target communication protocol
  - Should work with existing satellite (e.g. simple bent-pipe satellite)
  - Configurable according to satellite characteristics (UL-G/T, DL-EIRP)
- Different user terminals in a network
  - Mobile terminal
    - very small antennas which can be installed on any car
    - Small (e.g. 40cm) antennas which can be installed on trucks etc.
  - Antennas for fixed installation
  - Local head quarter with “large” (1 – 3m) antenna diameter
- Communication characteristic are not only one-to-one
Resulting requirements

- Support of different terminal types requires support of different antennas
  - LP (Low profile): Very small, can be installed on any car, mobile
  - HG (High gain): Standard terminal with medium size dish (40-60cm), optionally mobile
  - XG (Extra gain): Large antenna (e.g. 3m), used for local head quarters

- Support of different communication types
  - LP <-> LP: Voice calls
  - LP <-> HG: Voice calls, video uploads, regional coordination
  - HG <-> HG: Data exchange, eNB connectivity to core network
  - XG available: Communication with head quarter (Hub station or head quarter operational after days)
Link type characteristics

- Large discrepancies in the individual link budgets

### Uplink 30 GHz
- **High Gain (HG)**
  - EIRP: 45 dBW
- **Low Profile (LP)**
  - EIRP: 25 dBW

### Downlink 20 GHz
- **High Gain (HG)**
  - G/T: 13 dB/K
- **Low Profile (LP)**
  - G/T: -7 dB/K
Link type characteristics

- Power spectral densities

- Communication LP to LP
- Communication HG to HG
- Communication HG to LP

12-15 dB
Meshed Connectivity –
The link budget challenge

- **Situation:** Bent-pipe satellites typically assume high uplink EIRP
- In (pure) FDMA, several terminals are active at the same time
  - the effective uplink EIRP is the sum of the power of all active terminals
- **Drawbacks of (pure) FDMA**
  - Dynamic reconfiguration of symbol rate per terminal difficult to achieve (all terminals might need to move center frequencies)
  - Multi carrier operation of transponder requires higher back-off
    - For many scenarios it is difficult to bring the transponder into saturation anyway
  - Presence of multiple Tx terminals concurrently allows driving the satellite uplink properly
Meshed Connectivity – The link budget challenge

- TDMA shows major limitations for meshed connectivity
- Terminals transmitting a high instantaneous bandwidth can not drive the satellite input properly
- A minimum set of parallel FDMA carrier is required
  - Example given for small antenna dishes (40-60 cm)
  - Example for direct link between such terminals

![Graph showing C/N vs. Number of FDMA Carrier for different scenarios.]

Scenario: Direct link between small (e.g. 40 – 60cm) terminals

UL: Terminal > Sat
DL: Sat > Terminal
Insgesamt

TDMA
UL limiting factor
DL performance dominates
Meshed Connectivity –
The link budget challenge

- Solution: “enhanced FDMA systems”
  - MF-TDMA: Combines FDMA with TDMA
  - SC-FDMA: Well known from 4G (LTE)
- No “real” differences – just (important) details

<table>
<thead>
<tr>
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<th>SC-FDMA</th>
<th>SC-FDMA</th>
</tr>
</thead>
<tbody>
<tr>
<td>frequency hopping</td>
<td>Dynamic reconfiguration of Fcenter and BW</td>
<td>Localized carrier allocation</td>
<td>Distributed carrier allocation</td>
</tr>
<tr>
<td>For frequency selective fading</td>
<td>Highly flexible, Power efficient</td>
<td>Highly flexible, Power efficient</td>
<td>For frequency selective fading</td>
</tr>
<tr>
<td>High HW complexity</td>
<td></td>
<td>Low HW complexity</td>
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</tbody>
</table>
Meshed Connectivity – The link budget challenge

**MF-TDMA**
- Frequent carrier change
- Parallel demodulation of multiple (independent) TDM carrier

**SC-FDMA**
- Fixed time/frequency slots
- Flexible allocation of slots according to required resources
- Synchronous demodulations
Meshed Connectivity –
The link budget challenge

- Efficient meshed connectivity feasible only if some requirements are satisfied
  - Sufficient concurrent uplinks
  - Easy parallel demodulation of multiple carriers
  - Quick reconfiguration of terminal bandwidth
    - According to throughput needs and congestion situation
- SC-FDMA allows an efficient implementation of
  - A dynamically reconfigurable
  - Multi carrier demodulator
Technical Challenges – SOTM and tracking antennas

- In (Ku-/Ka-band) “satellite-on-the-move” systems, tracking antennas need to be used
- Main limitations:
  - Tracking antenna de-pointing (for high-gain, highly directive antennas)
  - Out-of-axis transmission (for low-profile, less directive antennas)
    - Regulations apply
Technical Challenges – SOTM and tracking antennas

- Uplink EIRP is also limited by interference constraints
- Defined by ITU S.524 or EN301459
- High pointing accuracy required (< 1°)

Example
- 40cm antenna
- 6dBW electrical power
- Allocated bandwidth 2.5MHz
Economical Challenges

- In order to be low in cost and high in acceptance, mobile satellite communication for disaster relief should benefit from the economy-of-scale of other application cases:
  - “meshed connectivity” should be available for a wider range of applications such that disaster relief is a “side application”
  - “mobile support” should be available also for a wider range of applications, such that disaster relief again is a “side application”
  - RF components, antenna tracking sub-systems and part of the baseband components should be “off-the-shelf”
- The solution must also be fully compatible to existing satellites in place
- Specific extensions (e.g. full on-board processing) should be avoided
  - On-board filtering could however be a nice research topic!
Way forward

- Our goal is to motivate
  - Wide industry support answering the real needs of disaster relief
  - Standardization of solutions to ease usage whenever / wherever necessary
- Standardization has a number of advantages:
  - Air interface is accepted by equipment industry and operators
  - Air interface is accepted by regulations (even allowing emergency satellite access or temporal extension of EIRP limits)
  - Access to commercial spectrum can even be granted by authorities for disaster relief operations
Main requirements of a disaster-relief communication system

- World-wide, unlimited usage
- No pre-installation required
  - (time / location of disaster mostly unforeseen)
- Low cost-of-ownership, including
  - cost of satellite capacity (EIRP, bandwidth)
  - On-ground infrastructure (if required)
  - Hardware and software development
  - Operation / training / shipment cost
- Efficient interconnectivity to other media
  - Internet, (mobile) core-networks, operation center
  - Backbone connectivity for mobile base stations
Main requirements of a disaster-relief communication system

- Support of a wide range of applications and QoS requirements
  - (Low) Latency
  - Different throughput requirements
  - Scalable reliability of communication
- No single point-of-failure
- Support of a high dynamic range
  - mobile and fixed operation
  - different types of antennas
  - scalable number of users
Conclusions

- This talk tried to motivate:
  - Equipment and Resources for communication shall be available everywhere on our planet since we never know where and when disasters occur
  - True infrastructure-less communication can only be established through use of satellite resources, and by means of equipment which is available in every country
  - The required equipment will only be made available if it can benefit from economy-of-scale, so the basis for a worldwide deployment is a well-accepted air interface standard incl. its rule of operation
References

- 6th Appleton Space Conference: Broadband Mobility via Satellite, A Technology Revolution, Marcus Vilaca, Inmarsat
- Prof. Albert Heuberger, “LMS Channel and Fade Mitigation Techniques”, Tutorial presentation, ASMS 2010, Cagliari
Fraunhofer-Gesellschaft

- Founded in Munich in 1949
- 60 institutes across Germany with a total staff of 22,000
- Five Fraunhofer Centers in the USA
- Representative offices and senior advisors in Asia, the Middle East and Moscow
- Total budget €1.8 billion with €1.5 billion of income generated from contract research

Headquarters in Munich
Fraunhofer IIS
Fraunhofer-Institute for Integrated Circuits

- Founded in 1985
- More than 750 staff
- Budget approx. €90 million
- Revenue sources
  > 75 % income from projects
  < 25 % public funding

- "HOME OF MP3"
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- Communication Networks
- RF Systems and Antennas
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- Navigation and Localization
- Embedded Systems & Software
- Logistics and Service Development
- Medical Technology
- Defense and Security
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Tracking antenna test range

- FORTE: Facility for Over-the-air Research and Testing
- »SatCom« research platform
  - Complete emulation of a satellite link for testing of mobile terminals
  - Includes test range for tracking antennas in Ku- and Ka-band
- »MIMO-OTA« research platform
  - Universal over-the-air test environment
  - Wave-field synthesis for wireless devices up to 3 GHz
About the speaker

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Thanks for your attention!

Image taken at our DVB-SH transmitter site in Erlangen