5G – ENABLING RELIABLE LOW LATENCY COMMUNICATION FOR CONNECTED INDUSTRIES

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1880-1940s electrification of households from centralized power stations

- Replace gas/oil lighting with electric lighting
  - brighter light
  - reduced fire risk
  - cleaner
THE POWER OF TRANSFORMATION
EXAMPLE: HOUSEHOLD ELECTRIFICATION

INSTALLATION

TRANSFORMATION

› Home appliances
  › Refrigerator, Freezer 1920/30s-
  › Stove 1930s-
  › Heating, ventilation, air conditioning 1920/30s-
  › Washing machine 1940s-
  › Dishwasher 1950s-
  › …

› Home electronics
  › Broadcasting (radio, TV) 1920s-
  › Personal computers 1930s-
  › Audio, phones, tablets, gaming, … 1970s-
  › Electric vehicles
  › Smart homes / buildings,
  › …
 › Mobile communication has revolutionized personal communication

 › Installed communication infrastructure
   › Ubiquitous availability at marginal costs
   › Broad capabilities and evolving

 › Enabler for industry transformation with digitized processes
A common network platform with dynamic and secure Network Slices
MACHINE-TYPE COMMUNICATION

**Massive MTC**
- Massive numbers
- Small data volumes
- Low cost
- Low energy

**Critical MTC**
- Very low latency
- Ultra reliable
- Very high availability

Cellular networks addressing new requirements
MACHINE-TYPE COMMUNICATION

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CRITICAL MACHINE-TYPE COMMUNICATION: GUARANTEED IN-TIME DELIVERY

Factory Automation ≤ 1 ms
Motion Control ≤ 1 ms
Remote Control 5-100 ms
Intelligent Transportation Systems 5 ms

Smart Grid 3-5 ms
Tactile Internet 1 ms
Process Automation 100 ms
Automated Guided Vehicle 15-20 ms

Numbers are examples, requirements vary within one application area
Ultra-reliable low latency communication

- Metric: 99.9999…-percentile

Focus on worst-case

CDF

100%

Guaranteed delay limit

latency

“Normal” reliability (e.g. mobile Internet)

- Metrics: peak, median, 95-percentile

Exploit opportunities of favorable conditions

CDF

100%

latency

Design Objective

- Guaranteed delay limit
- Focus on worst-case
- Exploit opportunities of favorable conditions
- "Normal" reliability (e.g. mobile Internet)
- Ultra-reliable low latency communication
Manufacturing cell with central controller communicating with sensors and actuators

Wireless communication enables more flexible configuration of manufacturing cells and communication with moving parts

Combination of high reliability and low latency not achievable with current wireless standards

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Motion control</th>
<th>Alarms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum end-to-end latency [ms]</td>
<td>0.5 to 1</td>
<td>1</td>
</tr>
<tr>
<td>Jitter [us]</td>
<td>&lt;1</td>
<td>–</td>
</tr>
<tr>
<td>Packet size [bytes]</td>
<td>10 to 16</td>
<td>2 to 10</td>
</tr>
<tr>
<td>Packet loss rate</td>
<td>$10^{-9}$</td>
<td>$10^{-9}$</td>
</tr>
<tr>
<td>Application availability</td>
<td>99,999 %</td>
<td>based on fixed links</td>
</tr>
</tbody>
</table>

 › Small message sizes
 › Periodic traffic
   - Time-triggered data generation (e.g. real time motion control)
 › Sporadic traffic and alarms
   - Event-triggered data generation
\[ 100 \mu s \text{ transmission time} \] (i.e. 10\textsuperscript{th} of the end-to-end delay budget)

- **Guarantee for successful in-time delivery** (reliability)
COST OF GUARANTEEING HIGH RELIABILITY

High reliability (e.g. $10^{-5} - 10^{-9}$)

- 50-90 dB fading marging

Rayleigh fading channel
REDUNDANCY THROUGH DIVERSITY

› Diversity may be obtained through
  – spatial diversity, and
  – frequency diversity
› Time diversity difficult due to latency constraint
› Coding needed to fully exploit frequency and transmit diversity

Diversity is key for ultra-reliable communications
Coding scheme
- Block code for packets < 10 bits
- Convolutional code for packets up to a few hundred bits

Code rate
- Rate 1/2 – 1/3 good for performance-bandwidth tradeoff
- Minimum distance need to be greater than diversity order

Higher order modulation
- For devices with good SNR for bandwidth efficiency
- To keep code rate low for reliability
- Maximum order limited by transmitter and receiver impairments (EVM)
High reliability
- Avoid own-cell interference, preserve interference margin towards uncoordinated interference sources
- Synchronized (slotted) access helps maintain user orthogonality
- OFDM as baseline

Latency: access slots ≤0.1 ms
- Frame structure enabling low scheduling latency
- Slot formatting enabling low processing delay and on-the-fly decoding
- No computationally intensive receiver operation

Traffic handling: support both periodic and sporadic traffic types
- Persistent scheduling for periodic traffic
- Dynamic scheduling or contention-based access for sporadic traffic
- All with high reliability and low latency
MULTI-CONNECTIVITY FOR HIGH RELIABILITY

› Robust connectivity via coordinated multipoint communication
  – via multiple sites
  – across multiple frequency layers

› Fallback to other RATs (e.g. LTE)
Network layout for optimized service performance
  - E.g. local functionality for delay optimization
ICT is an enabler for **industry transformation** based on digitized processes

– Cellular communications provides ubiquitous connectivity and broad capabilities

5G is addressing requirements of new use cases including **ultra-reliable low latency communication**

– Diversity via coordinated multi-point communication and robust coding for reliability
– Frame format for short delay and on-the-fly processing
– Flexible network architecture for service-optimized network design and deployment
– **Ultra-reliable wireless transmission within 1ms latency is possible**