First performance results for multi-node/multi-antenna transmission technologies
Contributors

Editors: R. Fantini (TI)

D3.2

Description of Work (Annex I)

D3.2 First performance results for multi-node/multi-antenna transmission technologies

This deliverable will provide first performance evaluation results for a first set of multi-node/multi-antenna transmission technologies and it will identify the relevant requirements implied by such technologies on the other work packages. It will further provide guidance on the multi-node/multi-antenna transmission technologies identified as most promising for further assessment.
Summary of Deliverable 3.2

› Current results of the TeCs of WP3

› Analysis of the most promising approaches of WP3 based on the current results

› Interactions inside WP3 (TeC complementarity) and cross WPs

› Appendix:
  - Simulation Alignment
  - impact on TCs
  - Detailed description of TeC Results
What is new in Deliverable D3.2?

› Before:
  - D3.1 has defined the structure of WP3 by Tasks and Research Clusters (RCs);
  - D3.1 also positioned the TeCs of WP3 with respect to the State of the Art

› D3.2 shows the current results of the TeCs:
  - By means of simulation alignment efforts along partners;
  - As a result of the positioning of the tasks
  - Identifies the most promising approaches according to current results
## WP3 Mapping to METIS goals

### T3.1 METIS goals addressed
- 1000x data volume
- 10-100x user data rate
- 10-100x number of devices
- 10x longer battery life
- 5x reduced E2E latency
- Energy efficiency and cost

### T3.2 METIS goals addressed
- 1000x data volume
- 10-100x user data rate
- 10-100x number of devices
- 10x longer battery life
- 5x reduced E2E latency
- Energy efficiency and cost

### T3.3 METIS goals addressed
- 1000x data volume
- 10-100x user data rate
- 10-100x number of devices
- 10x longer battery life
- 5x reduced E2E latency
- Energy efficiency and cost
WP3 Most promising technologies

› Here, the identified most promising technology approaches are listed.

› The Technology components (TeCs) are grouped according to their relation to the technology approaches.

› The technologies shown here are selected based on current results. Others are still working on results and might well be included in future documents;
Multi-antenna/Massive-MIMO

T3.1

Task Leader: Rajatheva Nandana (OUULU)
<table>
<thead>
<tr>
<th>TeC #</th>
<th>Short Title</th>
<th>Short description</th>
</tr>
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<tbody>
<tr>
<td>TeC 1</td>
<td>Large Aperture Massive MIMO</td>
<td>Development of low-complexity and energy-efficient multi-antenna transceiver techniques for Large Aperture Massive Array Systems</td>
</tr>
<tr>
<td>TeC 1b</td>
<td>DFT-SM-MRT</td>
<td>Discrete Fourier Transform (DFT) based spatial multiplexing and maximum ratio transmission for mm-wave large MIMO</td>
</tr>
<tr>
<td>TeC 2</td>
<td>Coordinated Pilot and Data RA in multicell massive SIMO System</td>
<td>Coordination of resources used for pilot and data transmission in a multi-cell massive Single Input Multiple Output (SIMO) system. Goal of the coordination is to mitigate pilot contamination and reduce inter-cell interference.</td>
</tr>
<tr>
<td>TeC 4</td>
<td>EVD-Based blind Channel Covariance estimation</td>
<td>Analyse the performance of eigenvalue decomposition (EVD) based blind channel covariance estimation methods and compare them with ideal multi-path extraction, also to investigate the feasibility of massive MIMO systems with non-reciprocal duplex channels.</td>
</tr>
<tr>
<td>TeC 5</td>
<td>Model Based Channel Prediction (MBCP)</td>
<td>Exploit detailed knowledge of the eNB environment in form of an accurate building vector data map (BVDM) for channel prediction. UEs feedback their relative location on the BVDM and the eNB reconstructs the wideband radio channel based on this information.</td>
</tr>
<tr>
<td>TeC 6</td>
<td>Predictor Antenna Array for fast moving vehicles</td>
<td>Adaptive Large MISO Downlink with Predictor Antenna Array for very fast moving vehicles</td>
</tr>
<tr>
<td>TeC 7</td>
<td>M-MIMO-MMW</td>
<td>Massive MIMO (M-MIMO) transmission using higher frequency bands based on measured channels with CSI error and hardware impairments</td>
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</table>

RC1: Effect of real world impairments and related enablers
RC2: Further studies on Massive-MIMO precoding schemes under ideal assumptions

<table>
<thead>
<tr>
<th>TeC #</th>
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<tbody>
<tr>
<td>TeC 8</td>
<td>Massive MIMO and ultra dense networks</td>
<td>Study of a TDD based network architecture with the aim of integrating a massive MIMO macro network with a dense layer of small cells (SCs).</td>
</tr>
<tr>
<td>TeC 9</td>
<td>Multi-cell MU massive MIMO maximizing weighted sum rate</td>
<td>Transmit and receive processing in multi-cell multi-user massive MIMO systems</td>
</tr>
<tr>
<td>TeC 10</td>
<td>Decentralized Transceiver Design</td>
<td>To obtain simplified transceiver processing methods based on random matrix theory</td>
</tr>
<tr>
<td>TeC 11</td>
<td>Massive SDMA with a LSAS</td>
<td>A LSAS is used to apply massive SDMA exploiting elevation and azimuth beamforming. Instead of increasing the SINR of several users the beamforming gain is used to serve as many users as antennas available in the spatial domain.</td>
</tr>
</tbody>
</table>
T3.1 Multi-antenna/Massive-MIMO
Massive-MIMO for in-band backhaul and for access

**Technology Approach:** Massive MIMO Backhaul
- Simplified precoding schemes (TeC1b) mm-waves
- Symmetric massive-MIMO (TeC1b) mm-waves
- Energy efficient high mobility (TeC6)

**Examples:**

Backhaul Backhaul and access share the same spectrum

**Expected Gains**

- Energy Saving: x1 to x30
- BLER: x1 to x100

**Expected Gains**

- Complexity reduction: x 3·10⁻⁵
- Spectral Efficiency: x 166.
**Technology Approach:** Massive-MIMO for Access

- 3D beamforming with CSI error (TeC7) cm-waves
- Multicellular- reduced complexity transceiver processing (TeC9,10,11)

**Examples:**

**Expected Gains**

Average SNR to achieve 20 Gbps throughput can be reduced by 17 dB at same transmitter power.

**Expected Gains**

Sum Spectral Efficiency and User Spectral Efficiency: 10X Baseline for comparison: LTE-A (8 antennas)
Advanced inter-node coordination

T3.2

Task Leader: Roberto Fantini(TI)
## T3.2 - Advanced inter-node coordination

### RC1: Further improvements to classical coordination techniques

<table>
<thead>
<tr>
<th>TeC #</th>
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<tbody>
<tr>
<td>TeC 1</td>
<td>CoMP Resource Allocation</td>
<td>Investigation of the impact of feedback and backhaul links on the performance of different multi-node transmission schemes. Multi-node resource allocation is proposed under imperfect feedback and backhaul channels.</td>
</tr>
<tr>
<td>TeC 2</td>
<td>Exploiting temporal channel correlation to reduce feedback in CoMP</td>
<td>An optimal feedback period is derived such that it guarantees same spectrum efficiency as using a conventional feedback scheme.</td>
</tr>
<tr>
<td>TeC 2b</td>
<td>DoF of MIMO BC and IC with delayed CSIT</td>
<td>Theoretical analysis of the Degree of Freedom (DoF) and net DoF of recent schemes for the MIMO IC and BC with delayed CSIT (DCSIT) and finite coherence time.</td>
</tr>
<tr>
<td>TeC 3</td>
<td>Distributed Precoding with Data Sharing</td>
<td>Precoding scheme for interference mitigation in multi-cell multi-antenna systems based on local CSI and data sharing</td>
</tr>
</tbody>
</table>
## RC2: Studies on Interference Alignment

<table>
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<tr>
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</thead>
<tbody>
<tr>
<td>TeC 4</td>
<td>Multi-User Inter-Cell Interference Alignment (MUICIA)</td>
<td>Design of multi-user selection algorithms in an OFDM based closed loop downlink transmission system. The transmit-precoding scheme is based on interference alignment in a multi-user multi cell network where both the transmitters and the users are equipped with multiple antennas.</td>
</tr>
<tr>
<td>TeC 5</td>
<td>Semi-distribute IA with PC convergence speed up</td>
<td>Semi-distributed algorithm to find the optimal filters at the BSs and UEs that achieve a target SINR at each UE, with power control (PC) to reduce the number of iteration and check the existence of the optimal solution at the beginning.</td>
</tr>
<tr>
<td>TeC 6</td>
<td>Distributed schemes for MIMO ICs</td>
<td>The proposed schemes rely on forward-backward training in TDD systems, to iteratively refine both the transmit and receive filters. They also employ a so-called turbo iteration run at each transmitter / receiver to speed up the convergence.</td>
</tr>
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</table>
## T3.2 - Advanced inter-node coordination

RC 3: Coordination with enhanced network and UE capabilities

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<tr>
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<tbody>
<tr>
<td>TeC 7</td>
<td>Dynamic Clustering with Multiantenna Receivers (DCMR)</td>
<td>Develop a dynamic BS clustering and UE scheduling for downlink CoMP systems where the resource allocation scheme explicitly considers that UEs are equipped with multiple antennas.</td>
</tr>
<tr>
<td>TeC 8</td>
<td>NOMA</td>
<td>Non Orthogonal Multiple Access (NOMA) with multi-antenna transmission schemes.</td>
</tr>
<tr>
<td>TeC 10</td>
<td>Distributed JT-CoMP</td>
<td>Distributed JT-CoMP downlink based on limited CSIT in a dense FDD network with enhanced multi-antenna receive processing</td>
</tr>
<tr>
<td>TeC 11</td>
<td>DIAS</td>
<td>Decentralized interference aware scheduling (DIAS) approach suitable for D2D communication, based on the transmission of a reverse beacon to signal interference.</td>
</tr>
<tr>
<td>TeC 12</td>
<td>NA IS/IC receivers and ultra-dense networks</td>
<td>Network-assisted co-channel interference robust receivers for dense cell deployments</td>
</tr>
<tr>
<td>TeC 13</td>
<td>Interference mitigation based on JT CoMP and massive MIMO</td>
<td>In ARTIST4G a powerful interference mitigation framework has been developed based on joint transmission CoMP beside others for a 4x2 MIMO scenario. Identified limitations like limited coverage for indoor users and rank deficiencies in case of many simultaneously served users should be overcome by proper inclusion of small cells and massive MIMO.</td>
</tr>
<tr>
<td>TeC 14</td>
<td>Coordinated scheduling for two-way relaying with NC.</td>
<td>In this work we apply the coordinated scheduling approach for the two-way relaying with network coding (NC) and MIMO in TDD systems</td>
</tr>
<tr>
<td>TeC 15</td>
<td>Adaptive and energy efficient dense small cells coordination</td>
<td>Define coordination schemes that allows to switch off unnecessary small cells when traffic request is low</td>
</tr>
<tr>
<td>TeC 16</td>
<td>Non-coherent communication in coordinated systems</td>
<td>This work investigates non-coherent communication in systems where the users are connected to multiple transmission points.</td>
</tr>
</tbody>
</table>
T3.2- Advanced inter-node coordination

› Task 3.2 is mainly following an evolutionary path, exploring CoMP techniques that exploit future network or UE enhancements, or novel techniques based on Interference Alignment.

› More revolutionary approaches, including novel access techniques (DIAS for D2D, NOMA, non-coherent transmissions), are also considered, however results in this case are less mature.

› Most of the studies are currently assuming an LTE-like OFDMA based access, they might be extended to novel air interfaces: cross sessions with WP2 are planned in order to identify potential collaborations.
**T3.2 Advanced inter-node coordination**

*Technology Approach: CoMP with advanced UE capabilities:*  
UE enhancements can alleviate the coordination complexity burden on the network, allowing:

- to have simpler clustering techniques thanks to enhanced cancellation capabilities of multi-antenna UEs (TeC7),
- reducing the feedback requirements thanks to channel prediction algorithm in the UE receiver (TeC10)
- improving performance thanks to interference capabilities of UEs assisted by the network that provides interference information or transmission points coordination (TeC12).

**Expected Gains**

- Cell throughput: average gain from 10% to 20%
- User throughput: 5th perc. gain from 30% to 50%
- Spectral efficiency: average gain from 10% to 20%
- Realistic and less complex clustering due to UE capabilities
Advanced inter-node coordination

Technology Approach: CoMP with Massive MIMO

Massive MIMO can become an attractive complement in an interference management framework, overcoming some of the limitations identified with traditional antennas (limited coverage for indoor users and rank deficiencies for large number of simultaneous users) (TeC13).

Expected Gains

- Spectral efficiency: Expected Gain > 100% to ideally factor of 10 over LTE Release 8
- Capacity gain: factor of 10 to 100 with increasing number of small cells
Multi-hop communications/wireless network coding

T3.3

Task Leader: Elisabeth de Carvalho (AAU)
## RC1: Infrastructure-based relaying and wireless backhauling

<table>
<thead>
<tr>
<th>TeC #</th>
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<tbody>
<tr>
<td>TeC 1</td>
<td>Coordinated multi-flow transmission for wireless backhaul.</td>
<td>Devise transmission schemes for cellular networks consisting of BS, RSs and MSs, where RSs are used as a means to enable an efficient wireless backhaul solution.</td>
</tr>
<tr>
<td>TeC 2</td>
<td>IAR and RA in a mmW UDN</td>
<td>To enhance spectrum efficiency, sub-optimal low-complexity Interference Aware Routing (IAR) and resource allocation (RA) schemes are provided, taking interference into account for several multi-hop flows.</td>
</tr>
<tr>
<td>TeC 3</td>
<td>Virtual Full-Duplex Buffer-aided Relaying (VFD-BR)</td>
<td>To overcome multiplexing loss of half duplex relaying, concurrent transmissions of the source and a relay are allowed with interference cancellation exploiting more than two relays with buffer and multiple antennas.</td>
</tr>
<tr>
<td>TeC 4</td>
<td>Distributed Coding for the Multiple Access Multiple Relay Channel (MAMRC)</td>
<td>To reach high spectrum efficiency, non-orthogonal access techniques combined with wireless network coding are considered in a cooperative communication setting.</td>
</tr>
<tr>
<td>TeC 5</td>
<td>IDMA-based bi-directional relaying</td>
<td>The impact of Interleave Division Multiple Access (IDMA) is analysed in combination with network coding to identify efficient strategies regarding MAC/BC structuring, resource allocation and channel coding for bi-directional communication.</td>
</tr>
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</table>
## RC2: Infrastructure-less/infrastructure-assisted D2D and mobile relays

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<thead>
<tr>
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<tbody>
<tr>
<td>TeC 6</td>
<td>MIMO PLNC to expand D2D coverage</td>
<td>A relay assisted D2D communication is considered with all nodes having multiple antennas, where the relay performs physical layer network coding (PLNC). The D2D transmission uses the same frequency spectrum as cellular communication.</td>
</tr>
<tr>
<td>TeC 7</td>
<td>Cooperative D2D Communications (CD2DC)</td>
<td>The main objective behind the proposed scheme is to allow cooperation between cellular links and direct device-to-device communication links to increase the spectral efficiency, the cell throughput, the number of connected devices within the cell, and the cell coverage.</td>
</tr>
<tr>
<td>TeC 8</td>
<td>Open-loop D2D relaying.</td>
<td>This work extends the concept of multi-functional MIMO transmission to implement distributed space-time coding in networks with UE relays of limited capabilities.</td>
</tr>
<tr>
<td>TeC 9</td>
<td>D2D communications to Enhance VUE uplink</td>
<td>By using D2D communication and cooperating with each other, less energy is required to send the same amount of data of each active VUE in the cooperative transmission than the individual VUE-to-BS communications.</td>
</tr>
<tr>
<td>TeC 10</td>
<td>NC and MIMO in TDD system with relaying</td>
<td>In this TeC the two-phase two-way relaying scheme is investigated. The main focus in this contribution is put on the second phase where two different schemes are compared: network coding and MU-MIMO.</td>
</tr>
</tbody>
</table>
T3.3- Multi-hop communications/wireless network coding

› Revolution (wrt LTE): in-band backhaul and access in sub-mm and mm waves.
  - Comparison to wired backhaul or out-of-band relaying
  - Gain in spectral efficiency with control of interference.

› Evolution (wrt LTE): techniques for spectral efficiency gains
  - Buffer-aided relaying
  - Non-orthogonal multiple access schemes in conjunction with wireless network coding.
  - D2D: underlay or cooperative with cellular, moving networks
**T3.3 Multi-hop communications/wireless network coding**

Approaches support in-band Backhaul and access

*Technology Approach: Heterogeneous network, lower frequencies* (< 10GHz)

- Half duplex relaying using the principles of wireless network coding (TeC1)
- Get performance closer to wired backhaul using wireless network coding and proper power allocation (TeC1)
- Uplink Enhancement of Vehicular Users by Using D2D Communications (TeC9)
- Practical multiple access schemes used in conjunction with wireless network coding (TeC5)
- Buffer-aided relaying (TeC3) can further enhance spectral efficiency

**Wired BH vs Wireless BH**: How do we achieve the same performance using

- Wireless network coding
- Power adjustment at the BS
- New transmission methods based on Han-Kobayashi
**Technology Approach: Indoor dense mesh network at mm-waves (TeC2)**

- Practical setting with a very dense mesh network of access points
- Ray tracing based channel model
- Backhaul and access share the same spectrum
- Low-complexity routing and resource allocation schemes

**Expected Gains**

- **System Throughput:** 3–25bps/Hz depending on deployment scenario
- **Average User Throughput:** ~70Mbps–1.5Gbps @ 184MHz BW depending on load and number of AgN’s
- **Average User Delay:** 75–150µs depending on number of AgN’s
Appendix

some examples of Technology components reported in D3.2
Multi-antenna/Massive-MIMO

T3.1

Task Leader: Rajatheva Nandana (OUULU)
Backhaul - revolution

Benefit of TeC in UDN concept:

UDN wireless backhauling:
1. for Ultra Dense Networks: 10-100 meters range
2. for under-utilised spectrum: 10-100GHz carrier frequencies
3. for Spectral Efficiency: 512x512 MIMO, 100s of bits/s/Hz
4. for energy efficiency (achieved through spectral efficiency)
5. for cost efficiency: $3.10^4$ times less complex than SVD

HOW: Low complexity Massive Spatial Multiplexing
High Mobility-revolution

› Benefit of TeC in Moving Networks (MN) concept:

- Efficient and Robust Wireless Backhaul for 5G vehicular communications

MN wireless backhauling:
1. for Moving Networks: 0-300kmph
2. for ‘traditional’ spectrum: below 6GHz carrier frequencies
3. for Spectral Efficiency and energy efficiency: with M-MISO beamforming
4. for robustness: same performance at all speeds
5. for cost efficiency: to be studied

HOW: Predictor Antennas
Access - Evolution

› For tackling rapidly increasing data traffic, usage of higher frequency bands is widely studied for 5G mobile communication system

› DOCOMO has already verified 10 Gbps transmission employing 11 GHz band 8×16 MIMO by outdoor experiment

› For flexible introduction of higher frequency bands such as MMW, *Phantom Cell architecture* has been proposed:

In higher frequency bands, Massive MIMO is expected to improve bit rate and transmission quality

Activating high-performance massive MIMO requires **accurate CSI at transmitter** and **compensation for hardware impairments**
Throughput of 20 Gbps Massive MIMO

For same entire antenna array size, Tx antenna spacing was set to $2\lambda$, $1\lambda$, $0.5\lambda$ for $N_T = 16, 64, 256$

- Compared to $N_T = 16$, $N_T = 64$ gets diversity gain in addition to BF gain
- With $N_T = 256$, additional BF gain can reduce the required SNR to achieve 20 Gbps throughput by 17 dB and 6 dB compared to $N_T = 16$ and 64, respectively

LOS channel, $K = 10$ dB
16 streams
AMC

Average Throughput (Gbps)

Average SNR (dB)

$N_T = 256, 0.5\lambda$
$N_T = 64, 1\lambda$
$N_T = 16, 2\lambda$
Advanced inter-node coordination

T3.2

Task Leader: Roberto Fantini(TI)
Develop precoding strategies which utilize local CSI and exploit some form of data sharing among the BSs (e.g. the presence of **caching mechanism** in the BSs that stores frequently downloaded content) in order to mitigate the interference, and relaxing the backhauling requirements.

---

**Useful signals for the 3 mobiles**

- $v_1 = \mathbf{v}$
- $v_2 = -\mathbf{v}$
- Interference from BS$_1$ transmission to other mobiles
- Interference from BS$_2$ transmission to other mobiles

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**Graph**

- **DIA**
- **DIA-UPC**

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**Table**

<table>
<thead>
<tr>
<th>DIA</th>
<th>DIA-UPC</th>
<th>DIA-UPC</th>
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<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td>5</td>
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</table>
Find algorithms for user selection that maximises the performance of multi-user IA based transmit precoding, in order to maximise the system spectral efficiency. The approach is to find a pair of users that can benefit most from the alignment technique that aims to align intra-cell and inter-cell interference. Such a pair provides high system performance when IA is applied as transmission technique.

- Results with Multi-user Inter-Cell Interference Alignment (MUICIA) transmit precoding for different user selection methods.
- Cell rate performance enhances with the increase in the number of UEs
Dynamic optimization of clustering and scheduling maximizing the network weighted sum rate, with UEs equipped with multiple antennas able to implement an interference rejection combiner or to be served by multi-stream transmission.

- The developed dynamic clustering (DC) outperforms single cell processing (SCP), and static clustering (SC).
- Adding antennas at the UE IRC is able to strongly limit the inter-cluster interference.
Multi-hop communications/wireless network coding

T3.3

Task Leader: Elisabeth de Carvalho (AAU)
**T3.3 Multi-hop communications/wireless network coding**

**Approaches supporting in-band Backhaul and access**

*Technology Approach: Heterogeneous network, lower frequencies (< 10GHz)*

› Complementary technology components

TeC5 – Bi-Directional Relaying with Non-Orthogonal Multiple Access

Expected Gains

- Spectral Efficiency and User Throughput: 43% compared to non-optimized IDMA system

Gain in spectral efficiency for the optimized IRA coded system for symmetric rate requirements.
T3.3 Multi-hop communications/wireless network coding

Approaches support in-band Backhaul and access

**Technology Approach:** Heterogeneous network, lower frequencies (< 10GHz)
- Practical multiple access schemes used in conjunction with wireless network coding (TeC5)
- Buffer-aided relaying (TeC3) can further enhance spectral efficiency

TeC3 – Virtual Full-Duplex Buffer-Aided Relaying

**Expected Gains**

Spectral Efficiency:
- 45–100% compared to state-of-the-art HD relaying
- 30–400% compared to conventional SFD-MMRS

![Graph showing average end-to-end capacity versus SNR for different relay configurations.]
T3.3 Multi-hop communications/wireless network coding

**Technology Approach:** Indoor dense mesh network at mm-waves (TeC2)
- Practical setting with a very dense mesh network of access points
- Ray tracing based channel model
- Backhaul and access share the same spectrum
- Low-complexity routing and resource allocation schemes

**Expected Gains**
- System Throughput: 3–25bps/Hz depending on deployment scenario
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T3.3 Multi-hop communications/wireless network coding

Technology Approach: Indoor dense mesh network at mm-waves (TeC2)