Summary of Deliverable 4.2: Final report on trade-off investigations

Emmanuel Pollakis (HHI)

2014-08-26

Contributors

Editor: Emmanuel Pollakis (HHI), Chan Zhou (HWDU)

Authors: Osman Aydin (ALU), Zhe Ren, Mladen Bostov (BMW), Tilak Rajesh Lakshmana, Yutao Sui, Tommy Svensson, Wanlu Sun, Erik Ström (CTH), Liang Hu, Emmanuel Ternon (DCM), Gabor Fodor, Nadia Brahmi (ERICSSON), Emmanuel Pollakis (HHI), Chan Zhou, Ömer Bulakci (HWDU), Panagiotis Spapis, Alex Kaloxylos, Apostolos Kousaridas (NKUA), Petteri Lundén (NOKIA), Reza Holakouei, Michał Maternia, Venkatkumar Venkatasubramanian, Fernando Sanchez Moya (NSN), Marcin Rodziewicz, Pawel Sroka (PUT), Javier Lorca Hernando (TID), Ji Lianghai, Nandish Kuruvatti, Andreas Klein (UKL), Daniel Calabuig (UPVLC)

Internal reviewers: Gabor Fodor (ERICSSON), Zhe Ren (BMW)

External reviewers: Luis Campoy (TID), Matthias Hesse (NSN)

Summary

› Identification of trade-offs/design aspects present on the network layer
  - Examination of Technology Components (TeCs, technical solutions developed by individual WP4 partners) proposed in WP4 with respect to potential trade-offs.
  - Categorization of WP4 solutions in clusters related to different trade-offs/design aspects.

› Description of main challenges of a trade-off
  - Summary about the underlying problem of a trade-off and how to balance advantages and disadvantages.

Summary

- Overview on how WP4 TeCs address the trade-offs
  - Proposed TeCs are designed in different HTs:
    - Direct Device-to-Device (D2D),
    - Massive Machine Communication (MMC),
    - Moving Networks (MN)
    - Ultra Dense Network(UDN)
    - Ultra Reliable Communication(URC)
  - Trade-offs and design aspects have different impact for the respective application domain.

- Conclusion: General guidelines for a trade-off/design aspect aware TeC design.

Overview of WP4 trade-offs/design aspects

Key trade-offs

- Complexity vs. Performance
- Information Interflow vs. Throughput/Mobility
- Energy Efficiency vs. Network Capacity/Coverage

… and design aspects were identified

- Centralized vs. Decentralized
- Long-time-scale vs. Short-time-scale

TeC vs trade-off/design aspect mapping

› Relevance of trade-off for TeCs in WP4 tasks has been investigated:

T4.1

Trade-off	Technical Component TeC…																		
	1-A1	1-A2	1-A3	2	3	4-A1	4-A2	4-A3	4-A4	4-A5	5	6-A1	6-A2	6-A3	7-A1	7-A5	9	10	15
Complexity vs. Performance	x	x	x		x			x		x					x		x	x	
Centralized vs. Decentralized				x	x	x				x	x	x	x	x	x		x		
Long vs. Short Time Scale						x		x	x	x			x	x		x	x		
Information Interflow vs. Performance			x		x		x	x							x			x	x
Energy Efficiency vs. Performance											x						x	x	

T4.2

Trade-off	Technical Component TeC…											
	4	5-A1	7	9-A2	10	11	12	13	14	16	17	18
Complexity vs. Performance			x	x		x			x	x	x	
Centralized vs. Decentralized												
Long vs. Short Time Scale				x							x	
Information Interflow vs. Performance	x	x	x	x	x		x	x	x	x	x	x
Energy Efficiency vs. Performance	x							x				

T4.3

Trade-off	Technical Component			
	TeC2	TeC3	TeC4	TeC5
Complexity vs. Performance	x			
Centralized vs. Decentralized	x			
Long vs. Short Time Scale				
Information Interflow vs. Performance	x	x		
Energy Efficiency vs. Performance			x	x

*Trade-off analysis for remaining TeCs of WP4 was not available or not planed.

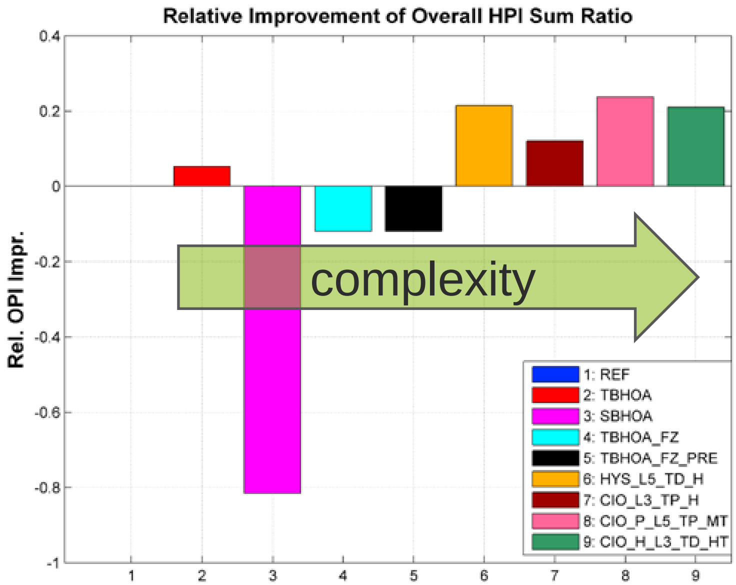
Complexity vs. Performance

› Key findings:

- Fundamental property of a mechanism which has an effect on a variety of METIS KPIs, where not all of them can be increased at the same time.
- The trade-off captures the balance between the **higher accuracy** of a mechanism, which in general is achieved with more complex mechanisms, and the **higher computational cost**.
- Especially **important for mobile devices**, as in practice they have only limited processing power and hard energy constraints.
- Even with the expected improvements in processing capabilities foreseen for the year 2020 and beyond the computational requirements will be infeasible in many applications.
- Potential technical solutions *may address the METIS goals*, but at the same time *fail to meet all TC KPIs* such as introduced extra cost (CAPEX/OPEX) for more computational power or the energy consumption induced by the calculations etc.

Complexity vs. Performance

› Example: T4.2- TeC7: Context aware handover optimization using Fuzzy Q-Learning
  - Main concept: Fuzzy Q-learning based self-optimization schemes to adapt handover (HO) parameter settings.
  - Complexity: Different schemes where proposed exhibiting different levels of complexity.
  - Performance: Measured in HO KPI sum ratio improvement which is a combined metric of, among others, HO failures, connection drops, ping-pong HOs.
  - Results: More complex schemes achieve better performance. Schemes that require most iterations for learning outperforms other schemes in terms of overall HO KPI improvement.
  - .



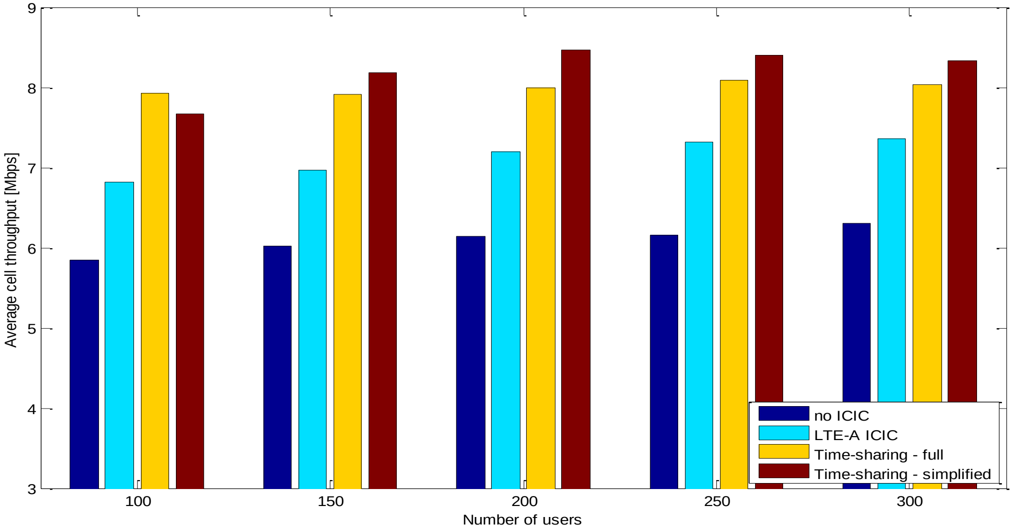
Centralized vs. Decentralized

› Key findings:
- *Centralized* approaches use a central entity that has a global view over all available resources and QoS requirements
  - Crucial part is the information gathering and storage.
  - Problem of **scalability** and introduced **delays**.
  - Are able to obtain **globally optimal** results in many cases.
- *Decentralized* methods obtain solutions in a distributed fashion.
  - Solve a network problem with using only **little information exchange**.
  - Often do not attain globally optimal solutions within practical time constraints
  - **Local optimum or good solution** improving the utility is acceptable when yielding low overhead, good scalability and robustness.
- This trade-off is of special *importance in the application domain of UDN and MMC* where networks usually consist of a huge number of nodes and the signaling overhead might degrade the QoS of Ues.

Centralized vs. Decentralized

› Example T4.1-TeC7-A1 Time-sharing for interference mitigation using resource auctioning and regret-matching learning

- Main concept: Distributed game theoretic approach to leverage interference leakage to neighboring cells. A periodic exchange of control information is required between the BSs
- Level of Centralization: Fully decentralized.
- Performance: Aggregate throughput per cell.
- Results: Compared to SOTA mechanisms (LTE-A eICIC) the mechanism achieves improvements of up to 15% (this might not be the global optimum).



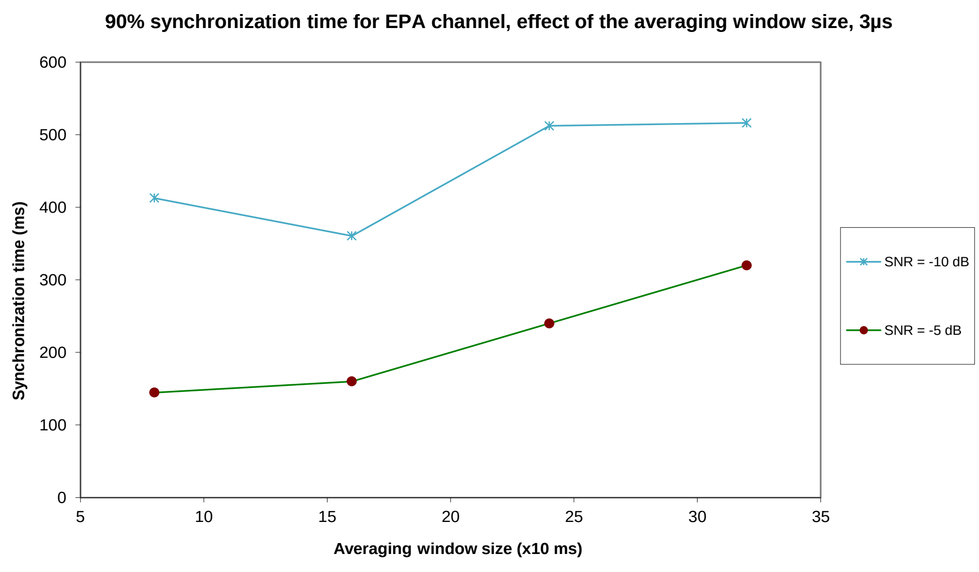
Long-time-scale vs. Short-time-scale

- Key findings:
  - This trade-off investigates the effect of the time scale on which a mechanism is operating
    - Closely connected to the dynamics present in the system.
  - Small time scale approaches are resulting in very flexible and adaptive mechanism with potentially high gains.
    - Good adaptability comes at the cost of the need for better system monitoring and signaling.
  - More static long time scale mechanisms
    - Less frequent information exchange.
    - Systems may be overprovisioned and thus inefficient.
  - **Future systems should adapt the time-scale of certain functionality to obtain close-to-maximum performance at strongly reduced effort**

Long-time-scale vs. Short-time-scale

› Example T4.1-TeC7-A5 Self organization of neighboring femto cell clusters

- Main concept: Self-organization of neighboring femtocell clusters by “Invited neighbor subscriber group” and synchronization via macro cell beacon signal. More accurate in phase operation of femto cells allows for higher downlink throughput.
- Time-scale: Variable from short to intermediate.
- Performance: Synchronization should be short in order to spend more time on providing service to users. Time for synchronization is related to the averaging window length. Low SNR beacons result in worse synchronization performance.
- Results: In low SNR situations (-10dB) the time required for synchronization is higher even with larger window sizes. Faster synchronization is achieved in higher SNR situations (-5dB) even with shorter window size.



Information Interflow vs. Throughput/Mobility

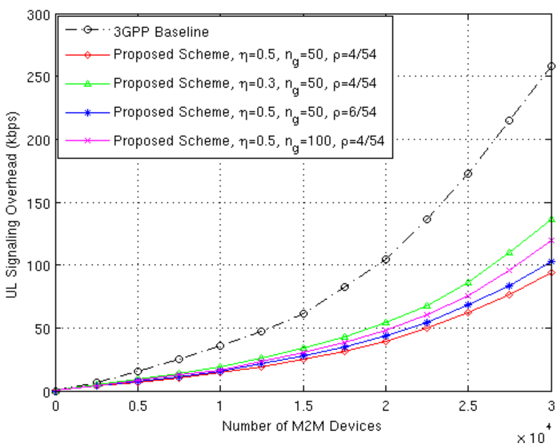
› Key findings:

- Impact of the amount of available *information for network management* on the METIS KPIs.
- Required information of the innovative 5G mechanisms is in general related to two aspects: **UE mobility** and UE-eNB/UE **channel state information**.
- *UE positioning* information enables the network to make sophisticated decisions regarding the radio resources to be allocated in a mobile terminal or to mitigate interference problems.
  - Exact positioning of the UE poses a heavy burden to the network for constant information flow.
- *UE-eNB/UE channel state information* enables the network to optimize its performance in terms of radio resource management (e.g., in interference mitigation cases or resource allocation).
- Increased signaling will pose a huge burden in the network especially for MTC communications in 5G.
- Periodicity of signaling and the type information which is exchange suggest a critical point for quantifying the benefits from introduced new schemes.

Information Interflow vs. Throughput/Mobility

› Example T4.2-TeC12 Context-based device grouping and signalling

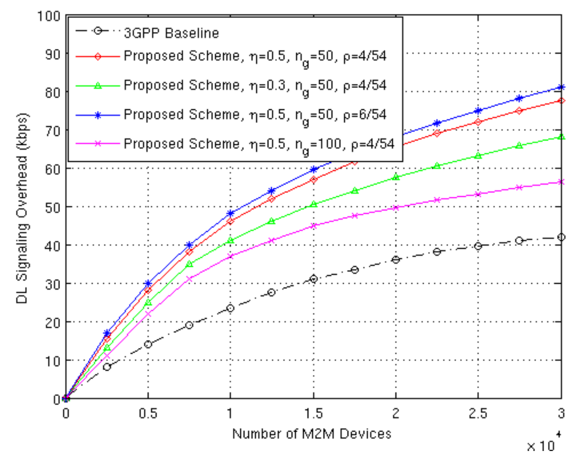
- Main concept: Reduce signaling overhead for MMC and mitigate possible congestion in signaling channel by context based device grouping and signaling.
- Signaling overhead: Reduced signaling overhead with gains depending on group size, RACH usage scheme and data redundancy.
- Performance: Signaling overhead for different group sizes, RACH usage schemes and data redundancy.



η: Percentage of redundant messages

ng: Group size

ρ: Percentage of RACH resources assigned to the group representatives



- Results: Significant reduction in overall signaling overhead especially for large number of devices. Compared with 3GPP TS37.868 the scheme reduces the signaling up to 50% in the uplink. In turn the downlink signaling overhead increases, but the gain in the uplink is larger as the loss in the downlink.

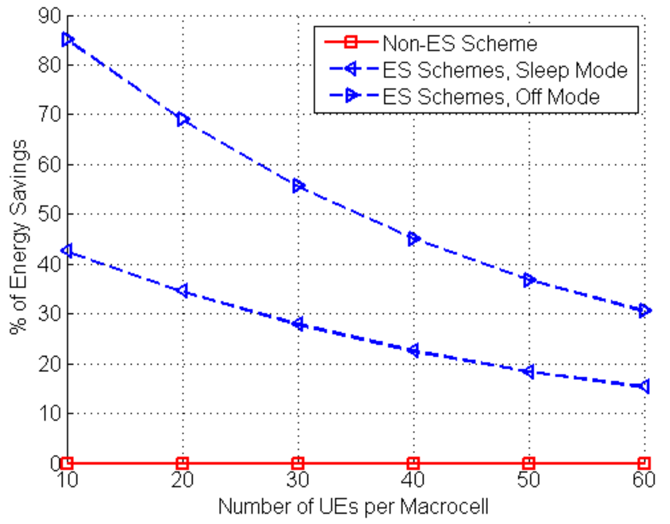
Energy Efficiency vs. Network Capacity/Coverage

› Key findings:

- Higher *capacity demands* call for the deployment of **more network elements** (base stations) which **increases the energy consumption**.
- In times the increased *capacity* is *not needed* the system is highly *energy inefficient*.
- A key to improved energy efficiency is to **identify the network elements that are exactly sufficient** to provide the requested capacity and coverage at every time instance.
- The energy consumption can also be reduced by **adapting the capabilities of each network element**.
  - Adjusting the cell range by *power control*, when taking into account the *interference coupling* in the system.
- *Relaying techniques* are beneficial towards a better use of energy.
- Major challenges include the capability of *assessing the service requirements* and user needs *in real time*, capturing the dynamics of the system and translating them to accurate capacity demands and *corresponding resource assignments*.

Energy Efficiency vs. Network Capacity/Coverage

› Example T4.3-TeC5 Self-management enabled by central database for energy savings in the Phantom Cell Concept
  - Main concept: Additional capacity in Macro cell area via small cells. Using the Phantom Cell concept and a database small cells are deactivated when not needed.
  - Energy efficiency: Improve energy efficiency by adapting provided capacity to required capacity.
  - Performance: Reduce energy consumption by avoiding overprovisioned system states.
  - Results: Database aided schemes can match the required service demand with a reduced set of active base stations. A "sleep mode" and a "off mode" is considered for small cells. Depending on the network load energy savings can be up to 80% and 40% with the "off mode" and the "sleep mode", respectively.



Conclusions

- Each solution needs to be tailored to its problem spaces and dynamics and thereby leading to efficient network operation with regards to timescales, accuracy, signaling, and energy efficiency.
- The different application domains in METIS have naturally different requirements and KPIs. Solutions have to taken into consideration the outlined trade-offs and leverage the disadvantages by carefully tailoring the mechanism to the application domain (D2D, MMC, MN, UDN, URC).
- Major trade-offs are signaling and complexity which can be derived from information flow vs. throughput/mobility enhancement or centralized/decentralized solutions trade-off.
- Future wireless communications systems will have to be able to instantly adapt its provided service (capacity) to the changing user requirements and meet them exactly with no overprovisioning. Therefore, the trade-off Energy efficiency vs. network capacity/coverage is strongly connected with the trade-off long time scale vs. short time scale. The faster the system can adapt the better the energy efficiency.

Conclusions

- There is a strong connectivity and interdependency of the identified trade-offs and design aspects
- When aiming at improved performance or no performance degradation the following observation can be used as a guideline.

	Centralized/Decentralized	Long/Short time scale
Complexity	• Centralized solutions allow for more complex operations • Decentralized solutions increase complexity by requiring additional coordination	• Short time scale adaptations require more computational power leading to higher complexity
Information Interflow	• Centralized solutions increase the Information Interflow as the information needs to be collected • Decentralized solutions in general have lower information interflow, however in case of heavy information exchange between coordinated nodes, it may even exceed load in centralized solution	• Short time scale mechanism exchange more information per time unit
Energy Consumption	• Investigated centralized approaches adapt better to system dynamics	• Time scale should be in the same order as system dynamics

Full version of D4.2 is available here

https://www.metis2020.com/wp-content/uploads/deliverables/METIS_D4.2_v1.pdf

https://www.metis2020.com