INTEGRAL PLANNING OF SERVICES IN SMART CITIES

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TNO innovation for life

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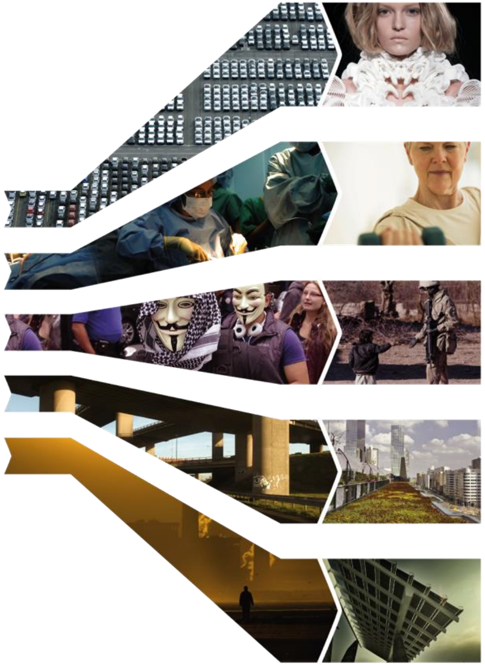
HEALTHY LIVING
DEFENCE, SAFETY & SECURITY
URBANISATION
ENERGY



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EXPERTISE GROUP
CYBER SECURITY & ROBUSTNESS

- We know how to
  - secure ICT systems and networks in order to preserve the privacy, confidentiality, integrity and availability of information in several contexts,
  - design reliable and robust ICT networks and systems, and
  - analyze and control the performance and behavior of complex ICT infrastructures.

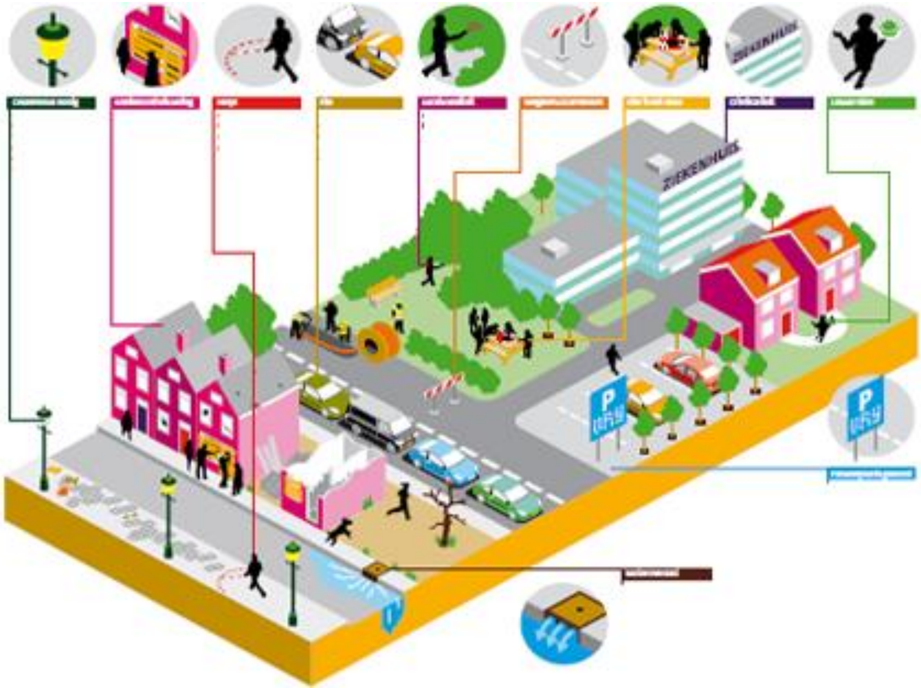
OUTLINE

INTEGRAL PLANNING OF SERVICES IN SMART CITIES

- SMART CITIES AND CHALLENGES
- PLANNING OF MULTI SERVICE NETWORKS
  - COVERAGE
  - CAPACITY
- CONCLUSIONS

CHANGING ENVIRONMENT

In our society the information density is condensing more and more. Not only the need for receiving information is increasing, but also the need for processing information gathered by, for example, sensors is increasing. Denser networks are required to be able to satisfy these increasing needs and to process all this data in an efficient way.



Source: Geonovum/TNO

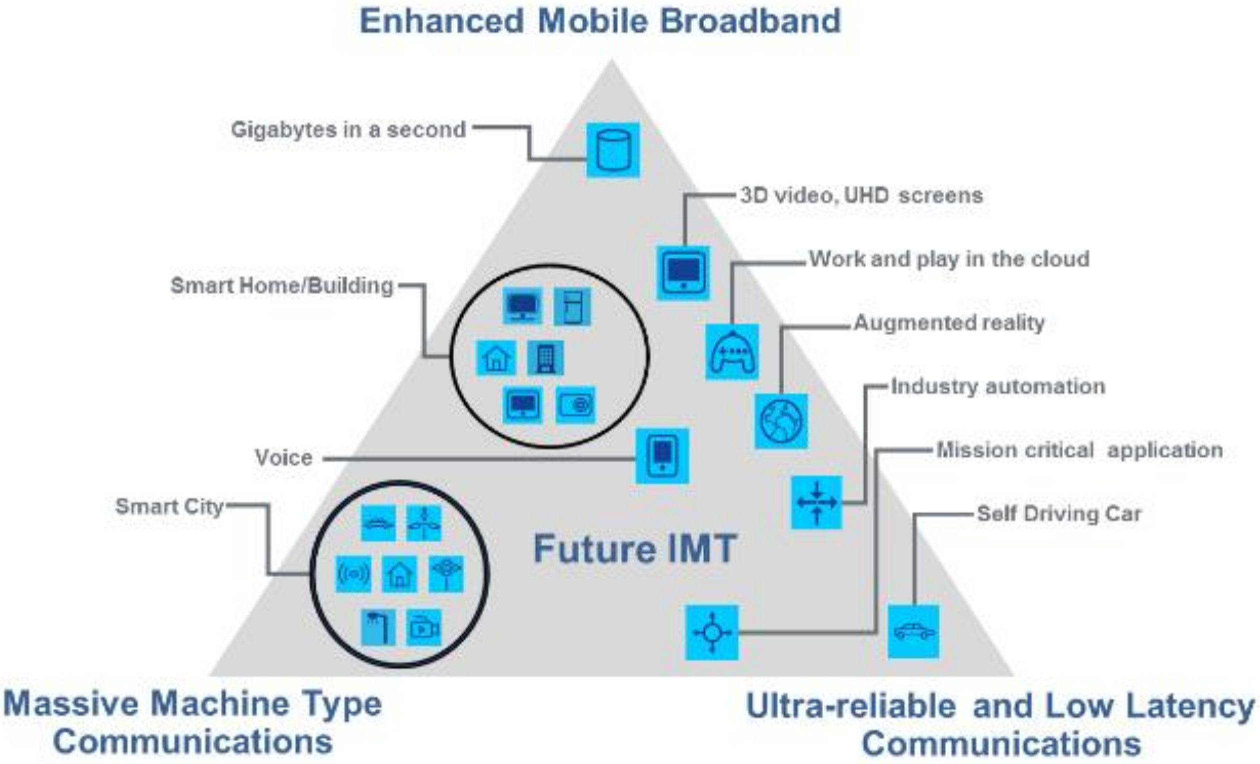
[Introduction to smart city (movie by VINCI Energies)]

NEW NETWORK DEMAND

New tasks in this smart city scenario:

- WiFi or 3/4/5G cell
- Camera setup point for safety
- Connection point for smart vehicles
- Air Quality Monitoring
- Flood control
- Alarm
- High bandwidth house connections
- Much more than we cannot think of now…

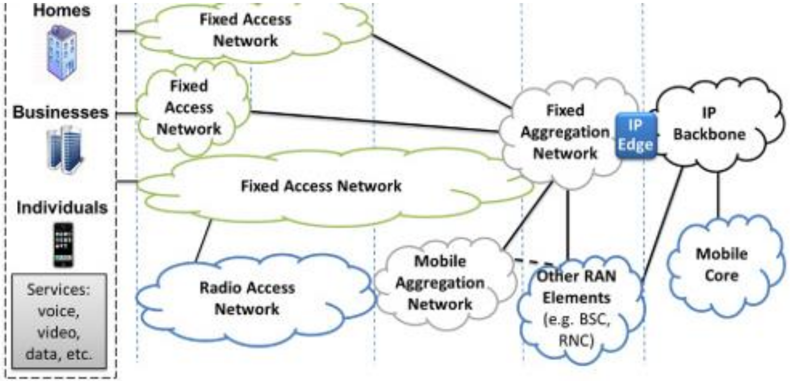
5G USAGE SCENARIOS

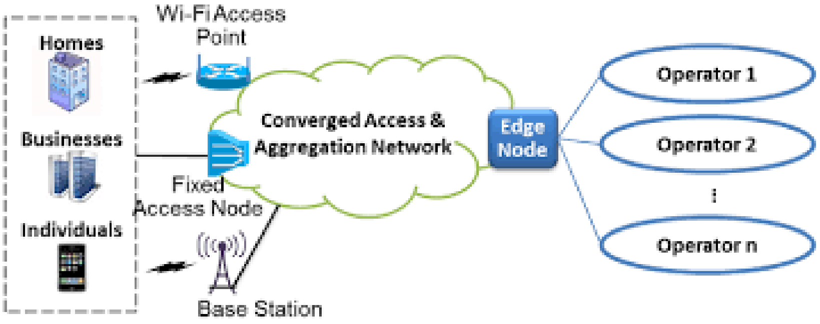


Source: Huawei/ITU ITU-R-defined 5G usage scenarios

FIXED MOBILE CONVERGENCE

- **Structural convergence**: pooling / sharing of network and infrastructure resources (cable plants, cabinets, buildings, sites, equipment and technologies) for several network types (fixed, mobile and Wi-Fi);
- **Functional convergence:** the implementation of a generic network function to realize similar goals in different network types (fixed, mobile and Wi-Fi).





Source pictures: Fixed and Mobile Convergence: Which Role for Optical Networks?, Stéphane Gosselin et al.

CHALLENGES

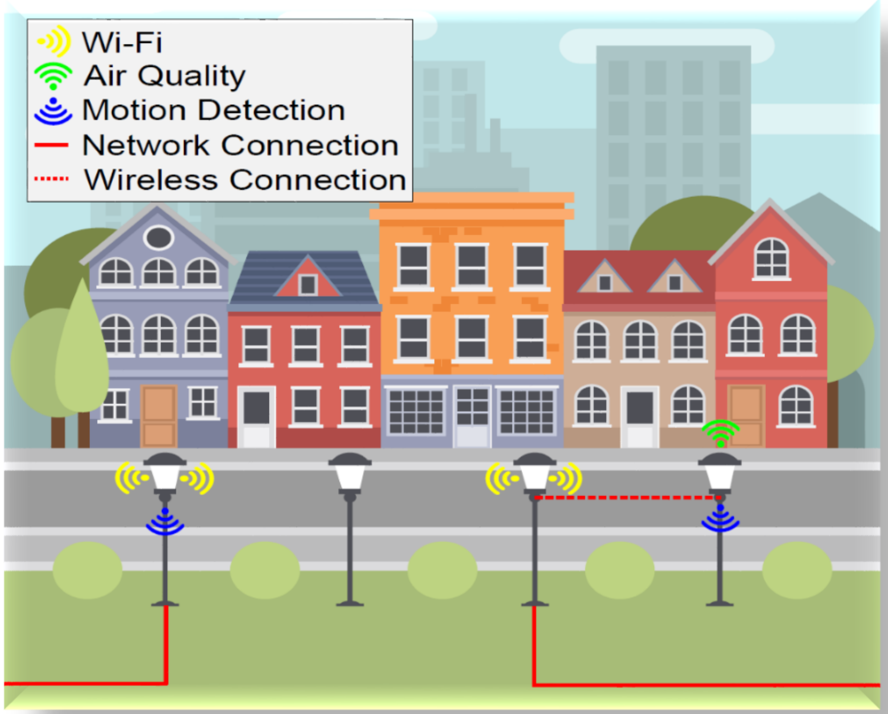
- The world is changing – on our way to a sensor based world – IoT – 5G – FMC – Self-X.

- Challenges
  - Technical - Functional
  - Performance - Resilience
  - Safety
  - Security
  - Planning - Robustness

STRUCTURAL CONVERGENCE: STREET FURNITURE AS ENABLER?

A potential enabler for access points of these networks is street furniture such as street lights and bus stops.

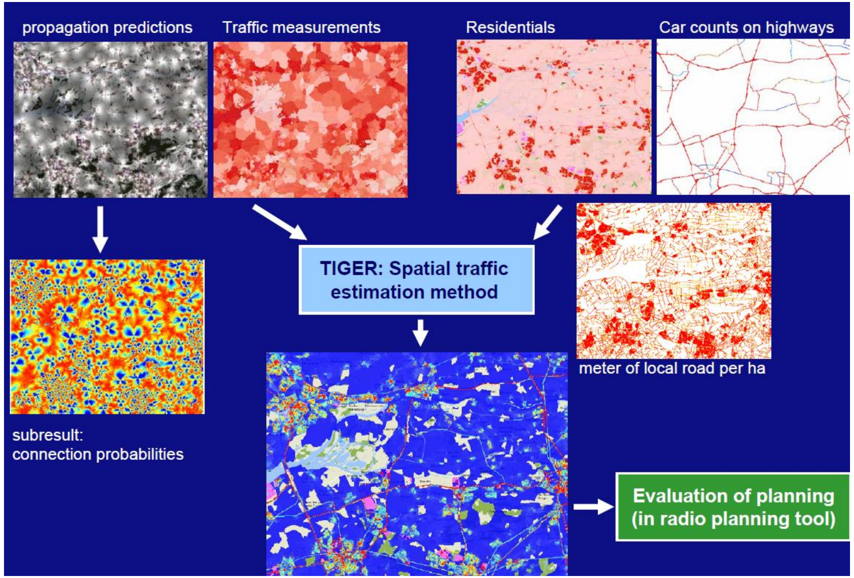
How to plan a network for all these services together?



EXISTING: SIMPLE VARIANT

- Mobile network planning
  - Single service
  - Coverage and capacity based
  - Advanced tools – interference and propagation

- Fixed network planning
  - Simple tools
  - Human planner



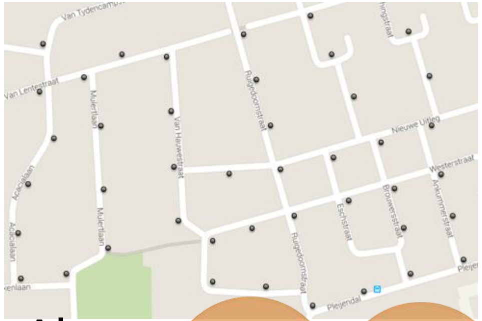
CHALLENGE

- Typical similarity for all these services access points is that they can or should cover a given area from a single location, but with different types of coverage range (in cell radius, direction, shape, etc). Next, there must be taken care of a connection to a backbone, for example, by fibre connections.

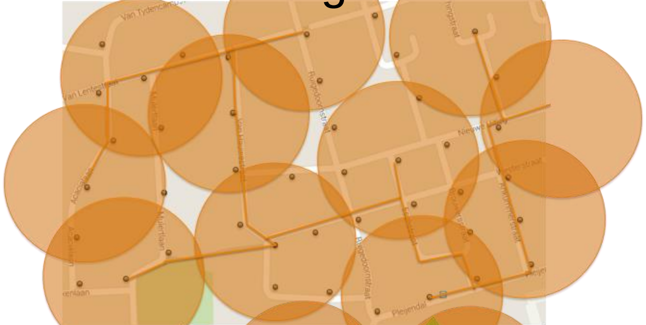
- The central question now is which (combination of) services are assigned to which of the (potential) sites such that all service requirements are met at minimum cost.

EXAMPLE COVERAGE

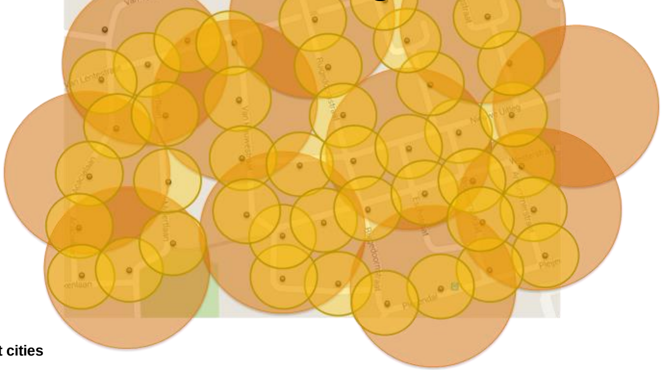
Urban area



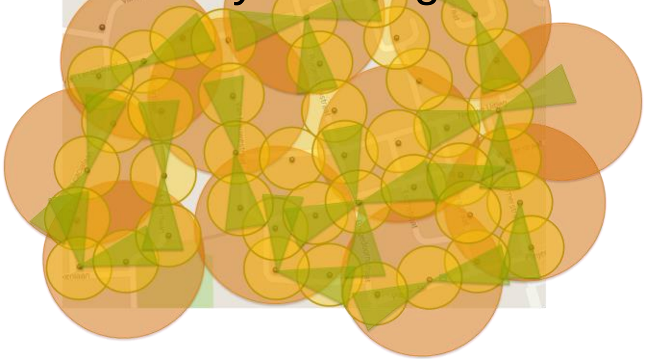
Wifi coverage



Alarm coverage



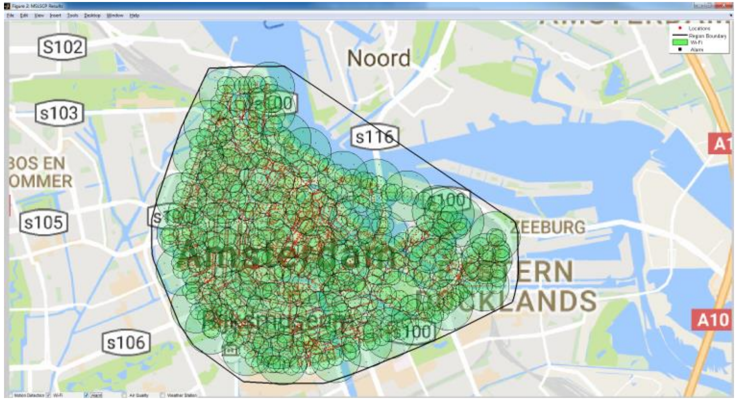
Security coverage

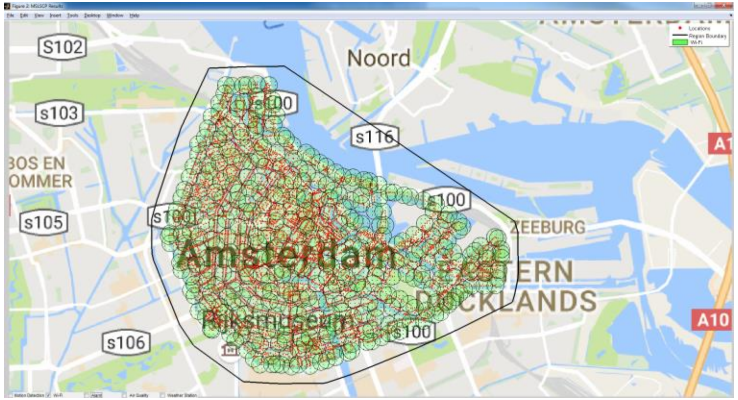


PROTOTYPE TOOL

- TNO created a prototype tool:
  - Minimizing cost;
  - Multiple services, coverage;
  - Covering streets, homes, hotspots;
  - Two layer coverage, central hubs;
  - Visualization.

- Based on smart mathematic core, solving a multi-service location set covering problem.






HOW?
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DISTRIBUTION OF THE SERVICES - DETERMINISTIC

1. Distribute the services over the lampposts such that coverage is reached.

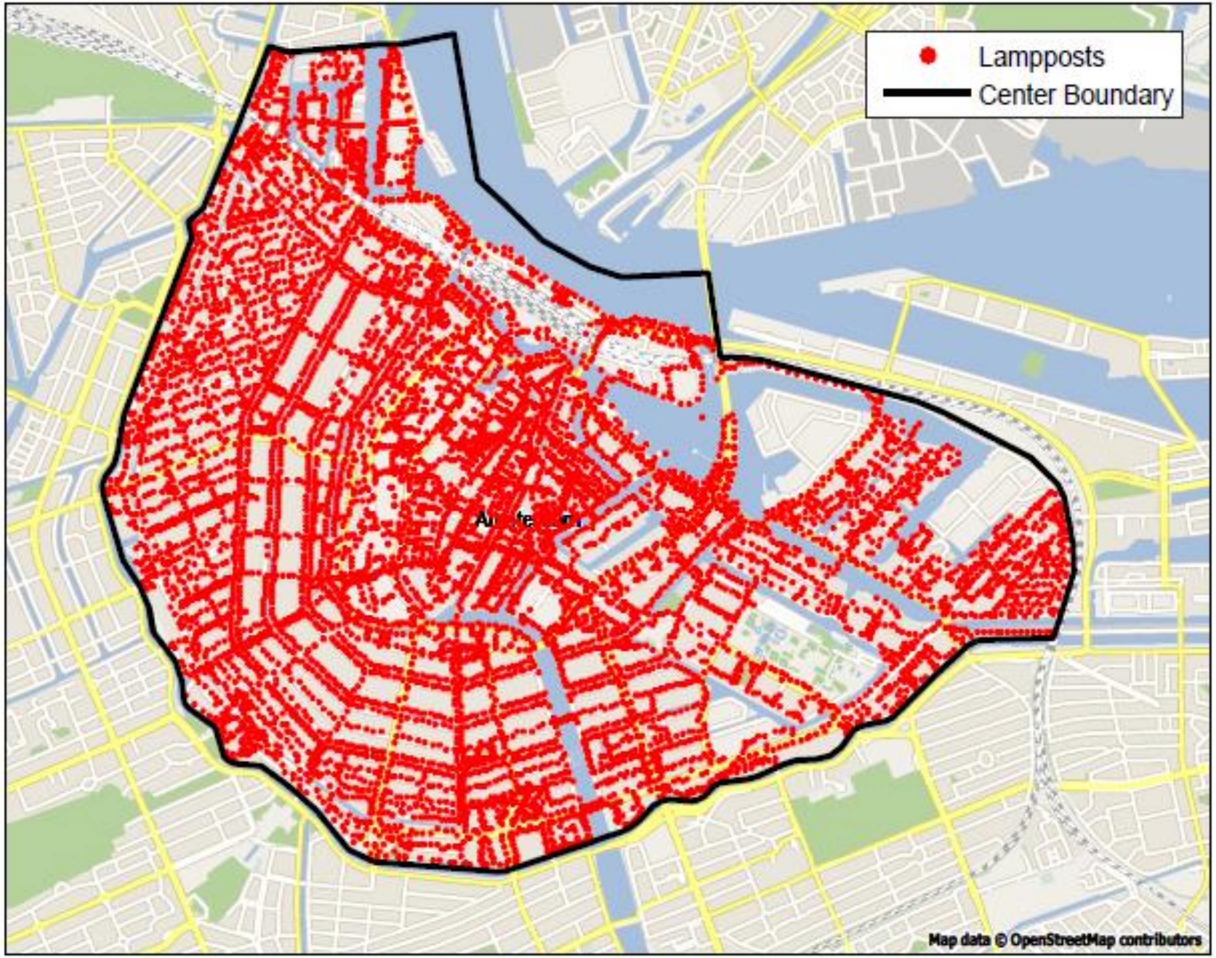
2. Search for hubs in selected lampposts.

Sources: 'Constrained Wireless Network Planning', T. Vos and F. Phillipson, 17th International Conference on Innovations for Community Services (I4CS), Darmstadt (Germany), 2017 and 'Using Lampposts to Provide Urban Areas with Multiple Services', T. Vos,. MSc Thesis, Erasmus University Rotterdam and TNO, 2016.

STEP 1: COVERAGE

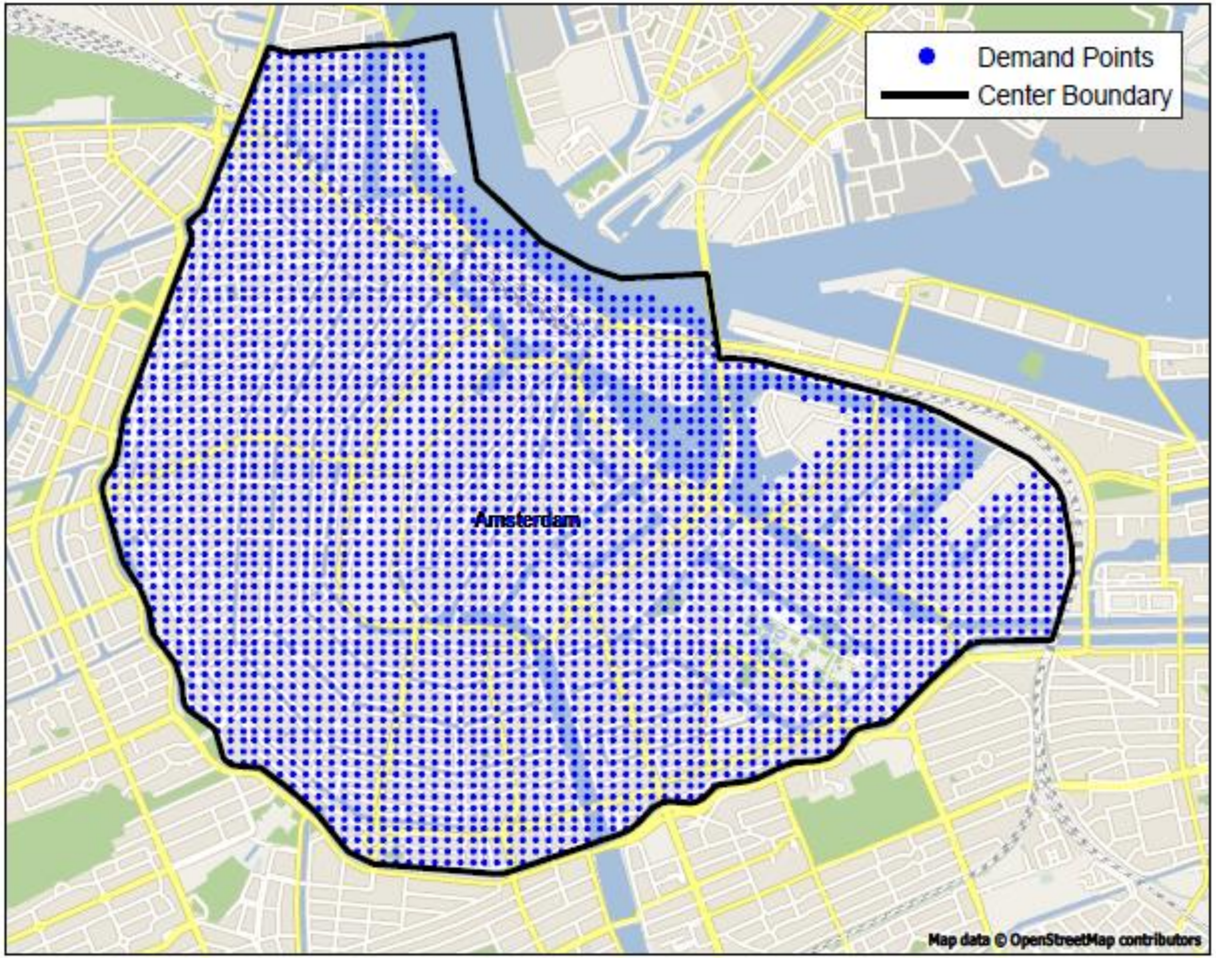
- Services have different coverage areas and coverage requirements.
- Fixed costs associated with enabling a lamppost to be equipped with services, independent of the number of services.
- Find a balance between individual and grouped distribution.

LAMPPOSTS

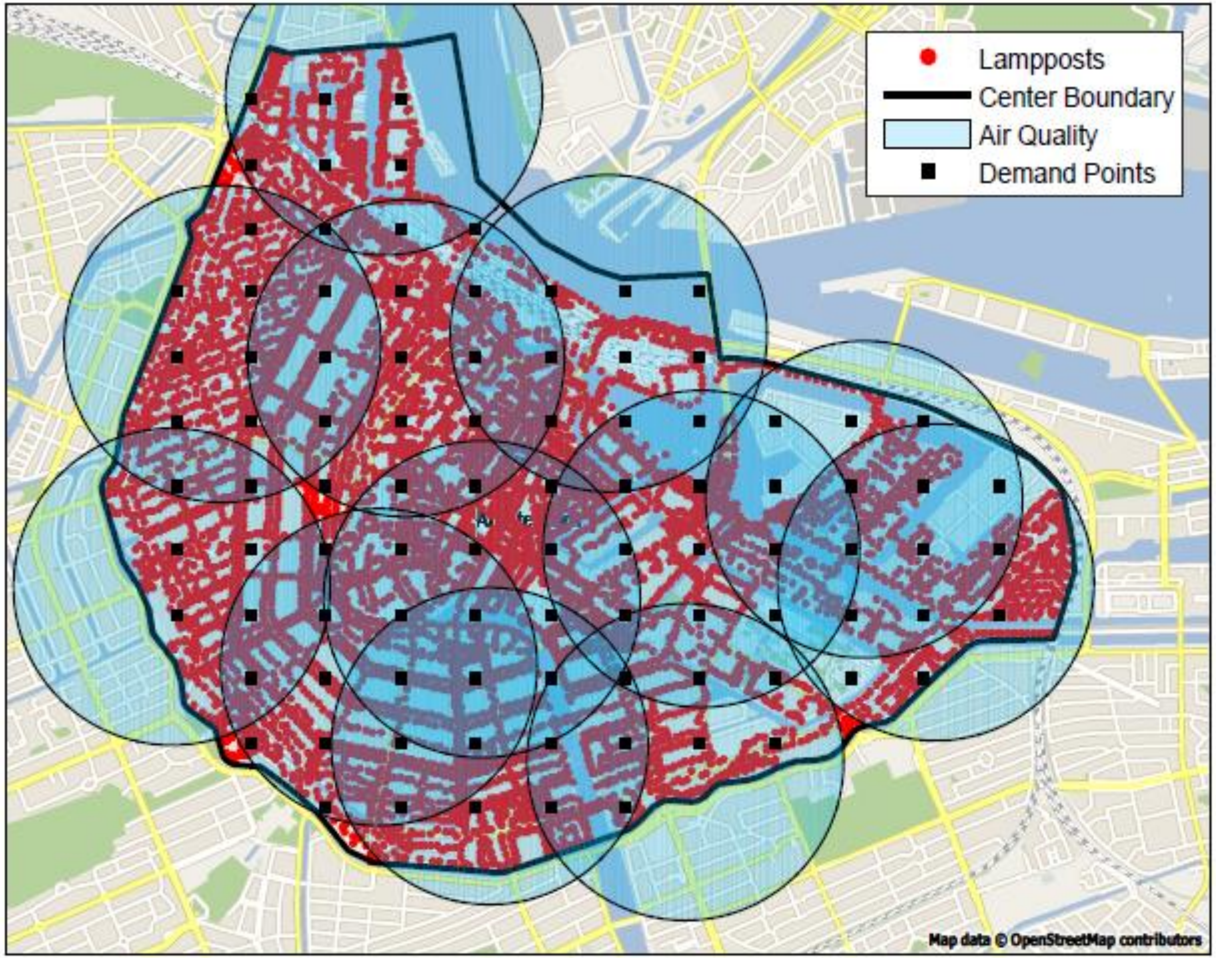

Lampposts
Center Boundary
Map data © OpenStreetMap contributors

DEMAND

- Any kind of demand point possible (e.g. houses, discretized streets, discretized region).



EXAMPLE


Lampposts
Center Boundary
Air Quality
Demand Points
Map data © OpenStreetMap contributors

MATHEMATICAL CONTEXT

- Combination of **Set Cover Problem** and **Facility Location Problem**.
- Both problems are hard to solve.

USED (HEURISTIC) METHODS

- Phase 1:
  - Sequential Set Covering Heuristic: several SC-steps
  - Likelihood Heuristic: start with the location with the highest coverage of demand points
  - Connection Heuristic: start with covering the demand points with the least options.
  - Use ILP-solver

- Phase 2:
  - Solve the smaller problem with ILP-solver

CASE STUDY

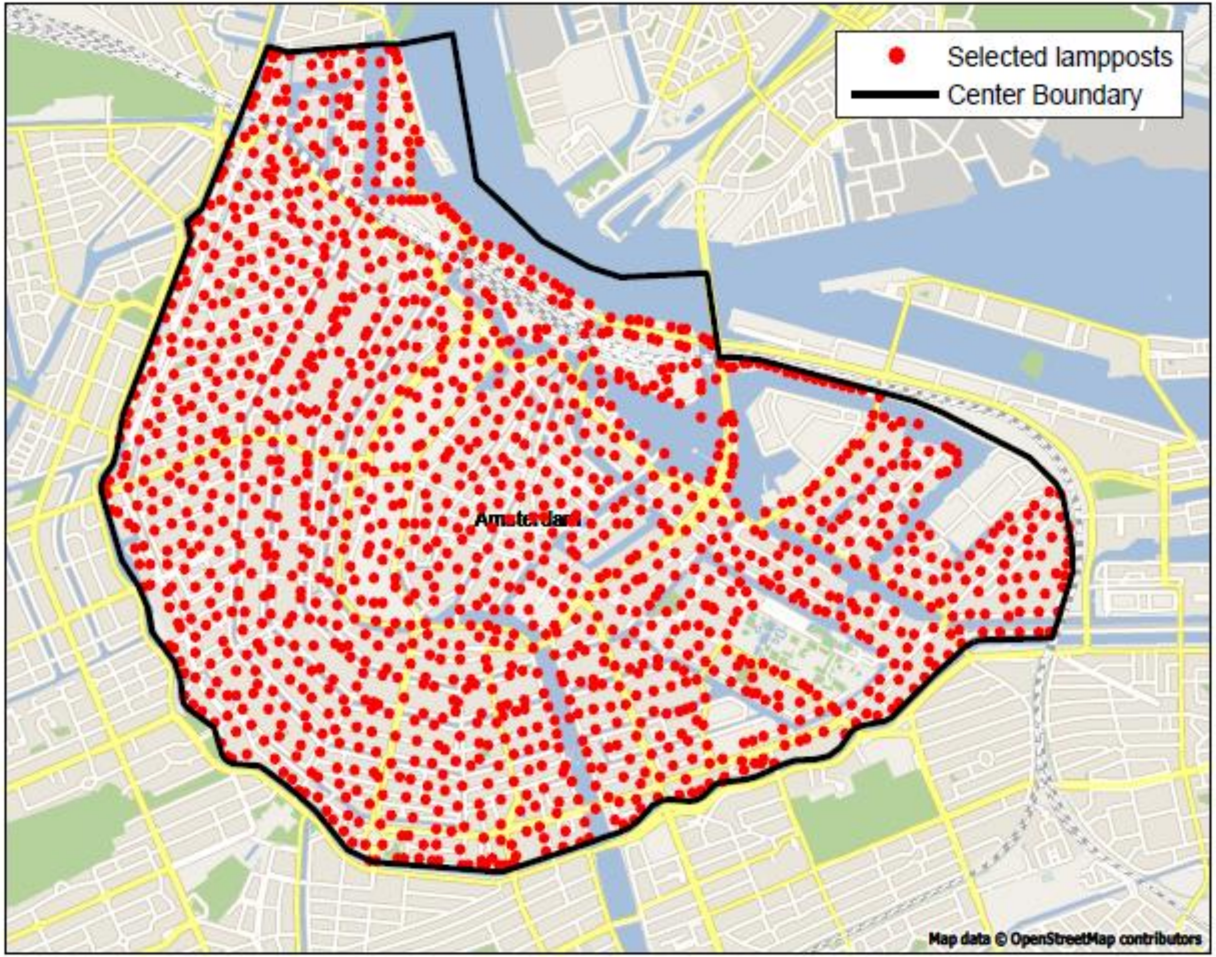
Service	Abbreviation	Specifications	
		Range (m)	Costs (€)
Wi-Fi	Wi	50	300
Motion Detection	MD	100	350
Alarm	AL	300	150
Air quality	AQ	650	400
Weather Station	WS	1,500	950

Service Area	Lampposts	Demand Points				
		Wi	MD	AL	AQ	WS
Schiermonnikoog	233	1,704	783	242	106	52
Rozendaal	523	1,736	653	116	40	16
Noordwijk	1,162	4,156	1,902	488	187	72
Lisse	4,273	10,172	3,692	724	194	43
Amsterdam Center	8,604	11,744	3,243	391	96	19
Delft	13,885	22,489	6,806	983	248	53

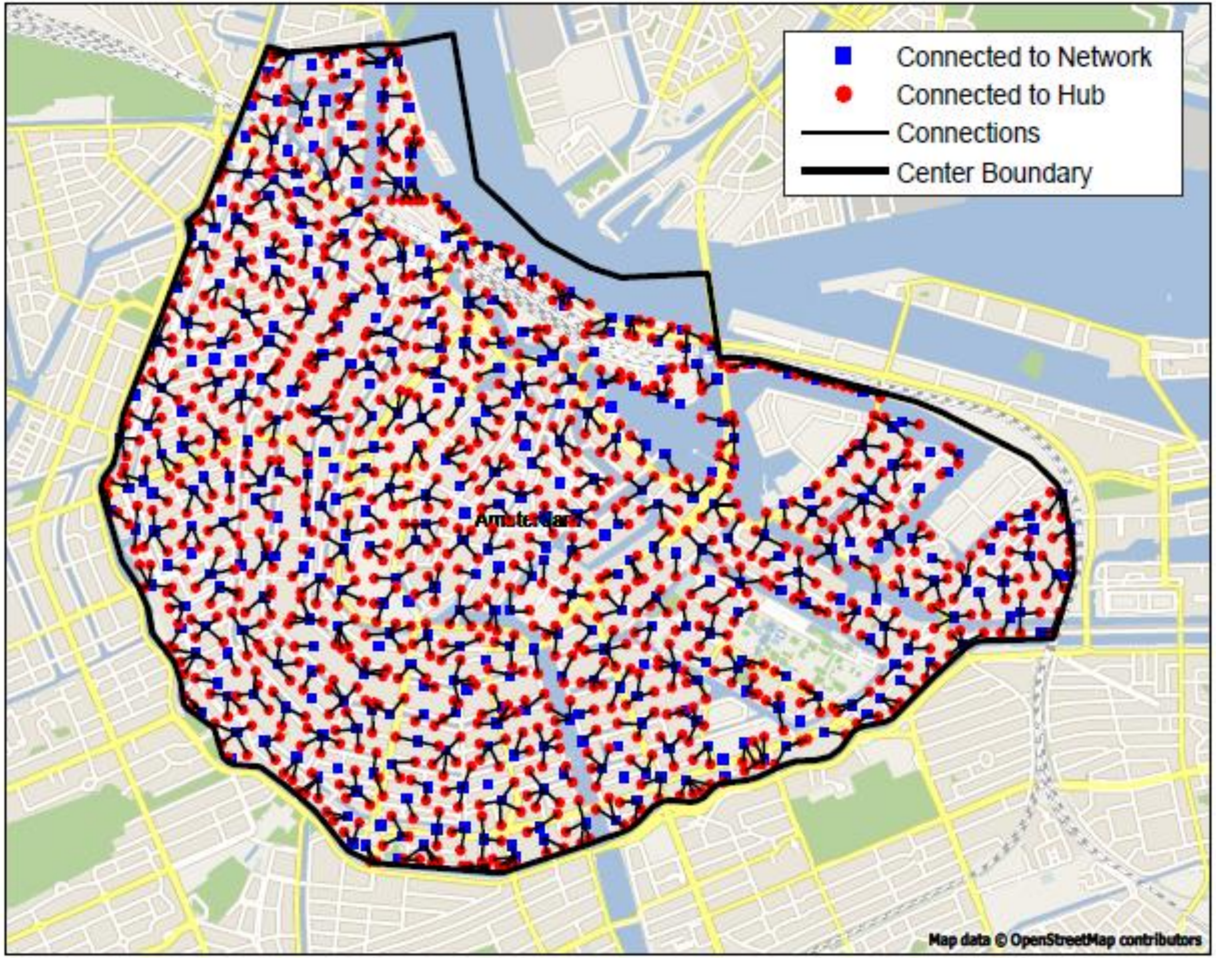
			Phase 1			Phase 2		
TC	LB (€)	Method	Obj (€)	Dev (%)	Time (s)	Obj (€)	Dev (%)	Time (s)
Schier monnikoog	528,291	MSLSCP Exact	528,889	0.11	0.12	-	-	-
		SSC Heuristic	528,889	0.11	2.33	528,889	0.11	0.07
		Likelihood	542,154	2.62	0.08	535,359	1.34	0.06
		Connection	592,924	12.23	0.19	554,192	4.89	0.06
Rozen daal	592,871	MSLSCP Exact	593,402	0.09	0.17	-	-	-
		SSC Heuristic	596,727	0.65	1.57	594,734	0.31	0.10
		Likelihood	636,001	7.27	0.16	610,854	3.03	0.14
		Connection	748,627	26.27	0.13	654,739	10.44	0.10
Noord wijk	1,692,027	MSLSCP Exact	1,692,594	0.03	0.55	-	-	-
		SSC Heuristic	1,706,116	0.83	3.66	1,696,606	0.27	0.11
		Likelihood	1,783,309	5.39	0.90	1,721,095	1.72	0.14
		Connection	2,017,122	19.21	0.89	1,823,728	7.78	0.17
Lisse	2,957,457	MSLSCP Exact	2,963,737	0.21	2,736.75	-	-	-
		SSC Heuristic	2,991,293	1.14	21.71	2,977,416	0.67	3.96
		Likelihood	3,167,800	7.11	6.43	3,056,816	3.36	234.32
		Connection	4,032,367	36.35	5.26	3,533,453	19.48	167.22
Amsterdam Center	3,236,138	MSLSCP Exact	3,255,959	0.61	†25,200.00	-	-	-
		SSC Heuristic	3,303,342	2.08	26.18	3,280,118	1.36	981.73
		Likelihood	3,609,602	11.54	14.27	3,449,529	6.59	†25,200.00
		Connection	5,130,907	58.55	10.24	4,362,125	34.79	4,083.67
Delft	6,918,375	MSLSCP Exact	6,947,421	0.42	†25,200.00	-	-	-
		SSC Heuristic	7,019,789	1.47	96.92	6,984,609	0.96	†25,200.00
		Likelihood	7,576,794	9.52	43.59	7,259,661	4.93	†25,200.00
		Connection	10,425,661	50.70	30.79	8,939,547	29.21	†25,200.00

STEP 2: HUBS

- Connecting access points very expensive.
- Find clusterings of a maximum of x lampposts of which one is designated as a hub.


Selected lampposts
Center Boundary
Amsterdam
Map data © OpenStreetMap contributors

CLUSTERING


Connected to Network
Connected to Hub
Connections
Center Boundary
Map data © OpenStreetMap contributors

ECONOMICALLY INTERESTING!

	MSLSCP		Exact WNP		
Service Area	Connected	Costs (€)	Connected	Costs (€)	Time (s)
Schiermonnikoog	163	441,049	55	120,478	0.15
Rozendaal	196	506,227	48	73,958	0.29
Noordwijk	544	1,434,866	142	233,330	2.00
Lisse	1,075	2,511,543	261	393,003	89.09
Amsterdam Center	1,401	2,729,674	307	357,287	1536.70
Delft	2,792	5,851,939	648	855,452	†25, 200.00

Technically feasible?

DETERMINE CONNECTIONS - ASSUMPTIONS

- For each lamppost assumed:
  - Same maximum range of wireless connection
  - Same capacity restriction

- Determine the connections:
  - Possible connections are known
  - For each lamppost the cost of designation as a hub is the connection cost

USED METHODS

1. Iterated Local Search: Greedy with restart from slight perturbated version of start solution
2. Greedy Randomized Adaptive Search Procedure (GRASP): Greedy with restart from random position
3. Simulated Annealing
4. Genetic Algorithm

	ILS			GRASP		
Service Area	Best	Avg	Time (s)	Best	Avg	Time (s)
Schiermonnikoog	134,851	135,450	0.21	132,874	134,140	0.76
Rozendaal	76,791	81,091	0.37	85,829	87,312	1.17
Noordwijk	255,015	256,550	2.15	267,084	279,010	10.94
Lisse	501,235	511,790	15.93	545,337	555,790	64.53
Amsterdam Center	516,017	538,388	32.25	550,556	561,990	136.65
Delft	1,186,504	1,196,515	147.39	1,276,910	1,287,202	318.24

	SA			GA		
Service Area	Best	Avg	Time (s)	Best	Avg	Time (s)
Schiermonnikoog	143,149	146,025	0.14	145,901	147,714	3.38
Rozendaal	93,514	96,734	0.23	95,074	99,251	5.17
Noordwijk	308,813	320,027	1.72	342,396	346,415	19.43
Lisse	550,193	551,091	12.37	612,893	620,898	75.62
Amsterdam Center	565,008	583,935	53.23	617,867	629,034	119.78
Delft	1,225,352	1,241,628	201.21	1,395,782	1,413,018	333.49

DISTRIBUTION OF THE SERVICES - STOCHASTIC

1. Distribute the services over the lampposts such that **coverage is reached and stochastic demand is met.**

2. Search for hubs in selected lampposts – **dimensioning of shared links**.

MODEL

- Multi service facility location problem with stochastic demand, approaches:
  - Chance constrained programming
  - Simulation
  - Recourse models
  - Queuing approach
    - Maximal Expected Covering Location Model
    - Queueing Maximal Availability Location Problem
    - Markov Decision Process

Work in progress…

CONCLUSIONS

- The world is changing – on our way to a sensor based world – IoT – 5G – FMC – Self-X.
- Technical challenges – safety & security challenges.
- Do not forget the planning – **smart planning can save a lot of money!**

MORE INFORMATION:

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