From WSNs to VANETs: paradigms, technologies and open research issues for challenged networks

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Keynote Talk I
WIDECOM 2019

Milano - Feb. 11, 2019

Outline

1. What are the “challenged networks”?
2. Applicative scenarios
3. Common aspects
4. State-of-the-art
5. Open research issues
6. Conclusions

What are the "challenged networks"?

- *"Networks characterized by challenges, such as fragile connectivity, network heterogeneity, and large delays"*[1]
- networks that move away from the classic Internet paradigm
  - scarce resources
    - thin devices: bandwidth, memory, computation...
    - limited MTU
    - bounded energy supply (batteries)
  - frequently changing network topology
    - battery discharge → duty cycle
    - unstable, lossy, noisy, low-power, broadcast links (wireless)
    - sparse and/or mobile nodes → highly likely partitions
    - long latencies ... waiting for a route to form
- in spite of this, novel applications that call for novel strategies

[1] K.A. Harras, M.P. Wittie, K.C. Almeroth, E.M. Belding, "ParaNets: A Parallel Network Architecture for Challenged Networks", Proc. 8th IEEE Workshop on Mobile Computing Systems and Applications, 2007.

Scenarios

- once upon a time there were... cell phones (*single-hop*)
- which led to research on MANETs (*multi-hops*)
  - still not very mobile, however → not yet *challenged*
- environment monitoring, urban sensing (WSNs)
  - EuroDeer, ZebraNet, GoodFood... and many many others!
- *Intelligent transport systems*, but also robots/drones (VANETs)
- deep-space, maritime and underwater sensor networks (DTNs)
- mobile social networks, *crowd computing* (OppNets)
- Smart cities, ambient intelligence, pervasive health...
  - *IoT*, D2D and M2M communication
- *Industry 4.0* → smart factory

...magnificent picture! But...

Common aspects

- data-centric communication
  - publish/subscribe paradigm
  - Content-centric / Information-centric / Named-data networking
- scalability to hundreds or thousands of devices
- security due to the wireless media (and in spite of poor computation resources)
- self-organization to minimize human intervention
- fault tolerance in spite of hostile environment (dust, humidity, temperature)
- heterogeneity of devices (and protocols?)
- localization

VANETs: state-of-the-art

(focused on Intelligent Transport Systems)

- ETSI big picture

- distinction between V2V and V2I

VANETs: state-of-the-art

- some protocols have been already (almost) standardized:
  - IEEE 802.11p for layers 1-2 (a.k.a. WAVE / DSRC)
  - GPS for autonomous localization
  - cellular networks for V2I communications
- *proposals* for higher layers:
  - Grid / Hierarchical Location Service, etc.
  - Greedy Perimeter Stateless Routing, Geographic Source Routing, etc.
- on one hand: market pushes for selling advanced solutions
  - sensors are now common for assisted driving: obstacle detection, driver attention monitor, park assist
- on the other hand: **premature** technology
  - automated driving cars already caused fatal accidents

DTNs: state-of-the-art

things are a bit easier...

- Bundle Protocol already standardized back in 2007 (RFC 5050)
  - but still ongoing process: version 7 published as Internet Draft in Nov.30, 2018.[2]
- DTNs already are among us!
  - underwater: prototype deployed in cooperation with NATO Undersea Research Centre[3]
  - underwater: LOON (Littoral Ocean Observatory Network) testbed by NATO STO Centre for Maritime Research and Experimentation[4]
  - Postellation: general-purpose DTN Cloud[5]
  - SourceForge projects: DTN2, ION (Interplanetary Overlay Network)

[2] S. Burleigh, K. Fall, E. Birrane, "Bundle Protocol Version 7". Delay-Tolerant Networking WG, draft-ietf-dtn-bpbis-12

[3] D. Merani, A. Berni, R. Martins, "DTN for Maritime and Underwater Sensor Networks", DTNRG session - IETF, 2012.

[4] J. Alves, J. Potter; P. Guerrini, G. Zappa, K. LePage, "The LOON in 2014: Test bed description". Proc. UComms 2014.

[5] M. Blanchet, S. Perreault, J.-P. Dionne, "Postellation: an Enhanced Delay-Tolerant Network (DTN) Implementation with Video Streaming and Automated Network Attachment". Proc. SpaceOps 2012.

OppNets: state-of-the-art

- a huge amount of literature about message forwarding
  - novel paradigm: store-carry-and-forward
- several alternative models of mobility, sociality and encounters ← a lot of datasets
- a handful of prototypes, mainly for research purposes
  - opportunistic jukebox; Ateneo On Fly (mediated by infostations)
  - infrastructures for rural areas: DAKNET (India); SNC (Lapland)
  - a few apps: Twimight (social networking); FireChat (messaging)
- but... technologies for non-mediated device-to-device communications not yet mature[6]
  - not too high radio range: in order to save power
  - we performed experiments for the sake of comparison[7]

[6] M. Conti, C. Boldrini, S.S. Kanhere, E. Mingozzi, E. Pagani, P.M. Ruiz, M. Younis, "From MANET to people-centric networking: Milestones and open research challenges". Computer Communications 71 (2015).

[7] M.P. Dazzi, "Wireless technologies for non-infrastructured networks", Master thesis, 2016. Supervisors: E. Pagani, A. Trentini.

WiFi Direct: throughput

- WiFi Direct to create ad hoc opportunistic networks
- NICs of different vendors compared (anonymized) on different devices
- subset of measures; results in Mbps

devices	25 MB	50 MB	100 MB	average
PC $\leftarrow$ netbook	12.0	11.2	10.4	11.2
PC $\rightarrow$ netbook	7.8	8.8	9.6	8.7
netbook $\leftarrow$ notebook 1	8.8	8.8	8.8	8.8
netbook $\rightarrow$ notebook 1	13.6	15.2	17.6	15.5
PC $\rightarrow$ Raspberry Pi	9.6	19.2	20.0	16.3
PC $\rightarrow$ notebook 2	4.6	7.2	7.1	6.3
PC $\leftarrow$ notebook 2	12.0	9.6	11.2	10.9
average	9.8	11.4	12.1	

- homogeneous buses produce better results: PC $\leftrightarrow$ RaspberryPi and netbook $\leftrightarrow$ notebook 1
- speed toward PC is higher than in other cases

WiFi Direct: reliability and latency

- same devices as before
- subset of measures; times in ms.

devices	#pkts	min	avg	max	#loss
PC ← netbook	815	0.77	2.44	71.84	0
PC → netbook	1891	0.72	23.00	768.58	1
netbook ← notebook 1	5791	0.63	101.92	2601.90	112
netbook → notebook 1	1555	0.70	16.18	431.15	0
PC → Raspberry Pi	844	1.09	2.88	129.12	0
PC → notebook 2	668	0.73	2.37	129.20	0
PC ← notebook 2	595	0.79	2.10	116.81	0

- the NIC equipping both netbook and notebook 1 has the worst behavior
- PC and netbook differ in both NIC and bus

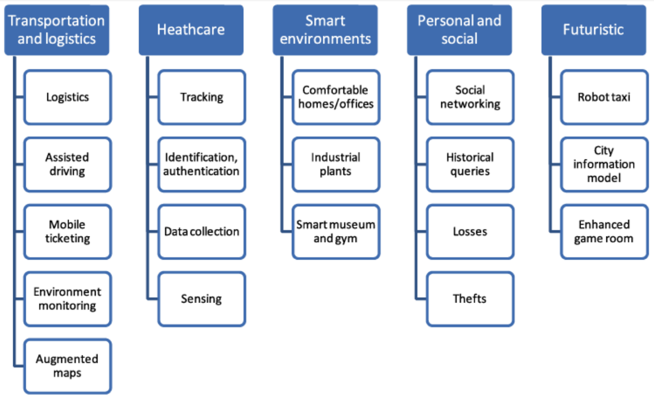
Lesson learnt: significative differences amongst devices of different vendors make performance highly variable

OppNets: other technologies

- Bluetooth is less power-consuming than WiFi but..
- so far, scatternet formation not yet standardized
- we implemented a simple solution which shows feasibility of the approach
  - synchronization amongst piconets impacts on latencies...
- BLE devices need a central coordinator in order to communicate $\rightarrow$ not adequate for OppNets
- LTE Direct: a bit of chronology
  - 2013: LTE Direct for Device-to-Device communication included in 3GPP-Rel12 (*completed in March 2015*)
  - 2015: first trials of LTE Direct performed by Deutsche Telekom
  - $>$ 2017: LTE Advanced Pro should also support V2V communications
- and 5G is about to arrive...

IoT: state-of-the-art

- *Definition:* "a world-wide network of interconnected objects uniquely addressable, based on standard communication protocols"
- pervasive, tiny, communicating devices in the environment

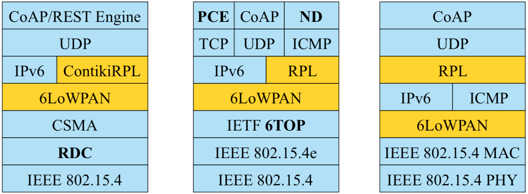


IoT: technologies

- commonly available platforms, such as Arduino, Raspberry etc.
- **IPv6** + (very) low-range communication technologies.

technology	bwth	radio range	frequencies	licensed
RFID (default)	40 Kbps	10 cm. - 1 m.	13.56 MHz	No (ISM band)
NFC	106-424 Kbps	$<$ 20 cm.	13.56 MHz	No (ISM band)
IEEE 802.15.4	250 Kbps	10 - 75 m.	2.4-2.5 GHz	No (ISM band)
BLE	1 Mbps	$\leq$ 50 m.	2.4-2.5 GHz	No (ISM band)

- brand new protocols, already implemented in available OSs



Contiki OS **OpenWSN OS** **RIOT OS**

plus possibly TSCH for:

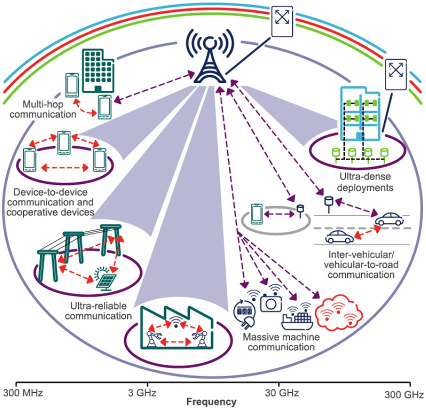
- reliability, latency and jitter guarantees
- security

Industry 4.0: state-of-the-art (?)

- *Industry 4.0 = IoT + cyber-physical systems + cloud + cognitive*
- some concurrent standards proposed for communications
- ZigBee $\neq$ 802.15.4 $\neq$ 802.15.4e
  - 802.15.4**e** is the version for industrial applications of 802.15.4
  - ZigBee adds functionalities to 802.15.4, at layers 3-4
    - mesh network, using P2P communications supported by 802.15.4
- 802.15.4 uses DSSS modulation and CSMA-CA channel access
- TSCH designed for industrial environment, uses time-slotted operations over 802.15.4 (TDM/FDM scheduling)
- WirelessHART uses TDMA/CSMA channel access in 2.4-2.5 GHz range over 802.15.4 physical layer
  - mesh network
  - TDMA guarantees deterministic performance
  - scheduling is not yet standardized: constraints specified

5th Generation

- unifying technology that should serve for smartphones, wearable devices, M2M, vehicles...
  - high data rate, massive IoT, low latency for mission critical apps
- multi-Radio Access Technology: ZigBee, WiFi, Bluetooth, LTE...

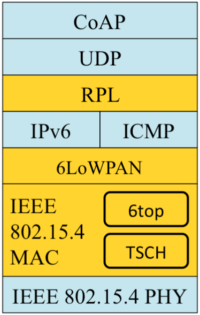


Open research issues

things start mixing...

- sensors, vehicles and human-carried devices will all be part of the IoT
- slow adoption of both IPv6 and 5G (and LTE Direct?)

- openness and standardization are critical!
- 6TiSCH WG[8]
  - 6top at sublayer LLC hides scheduling details
- roll WG
- 6lo WG: extensions to BLE, NFC and others
- and WirelessHART and...



[8] P. Thubert, "An Architecture for IPv6 over the TSCH mode of IEEE 802.15.4". Internet Draft draft-ietf-6tisch-architecture-19. Dec. 17, 2018

Conclusions

- "challenged networks" defined around 2001
  - huge advancements since then. Yet...
- need to understand in what directions standardization efforts move
- the set of technologies that are going to be used at layers 1-2 must become clearer, as well as their characteristics and services provided at upper layers
- technologies shall reach an adequate standardization level, stability, diffusion on users devices, and guaranteed compatibility amongst versions implemented by different vendors
- probably, higher layers' protocols shall also be re-defined
  - the design of upper layers must be done keeping in mind what really exists at lower layers
- need to deploy prototypes and testbeds to validate concepts
- do not disconnect from reality and make research progress together with the progress in technology availability