Bricks for future Mobile Networking

Brick 1: Data Offloading

Mobile Communication, WS 2014/2015, Kap.5

Prof. Dr. Nils Aschenbruck

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Data Offloading Techniques in Cellular Networks: A Survey

Filippo Rebecchi, Marcelo Dias de Amorim, Vania Conan, Andrea Passarella, Raffaele Bruno, and Marco Conti

***Abstract*—One of the most engaging challenges for mobile operators today is how to manage the exponential data traffic increase. Mobile data offloading stands out as a promising and low cost solution to reduce the burden on the cellular network. To make this possible, we need a new hybrid network paradigm that leverages the existence of multiple alternative communication channels. This entails significant modifications in the way data is handled, affecting also the behavior of network protocols. In this paper, we present a comprehensive survey of data offloading techniques in cellular networks and extract the main requirements needed to integrate data offloading capabilities into today's mobile networks. We classify existing strategies into two main categories, according to their requirements in terms of content delivery guarantees: delayed and non-delayed offloading. We overview the technical aspects and discuss the state of the art in each category. Finally, we describe in detail the novel functionalities needed to implement mobile data offloading in the access network, as well as current and future research challenges in the field, with an eye toward the design of hybrid architectures.**

***Index Terms*—Mobile data offloading, hybrid networks, WiFi, delay-tolerant networks, cellular networks.**

Scarce licensed spectrum hinders the RAN enhancements. Regulations allow mobile operators to use only a small portion of the overall radio spectrum, which is also extremely expensive. Users must share the same limited wireless resources. Adding traffic beyond a certain limit mines the performance and the quality of service (QoS) perceived by the users. During peak times in crowded metropolitan environments, users already experience long latencies, low throughput, and network outages due to congestion and overload at RAN level [2]. Unfortunately, this trend can only exacerbate in future due to the predicted mobile data explosion. The problem concerns primarily network operators because they have to trade-off customer satisfaction with business profitability, given the trend toward nearly flat rate business models. In other words, the exponential increase in traffic flowing in their RAN does not generate enough additional revenues to be allocated into further RAN upgrades. This creates what Mölleryd et al. call the *revenue gap* [3].

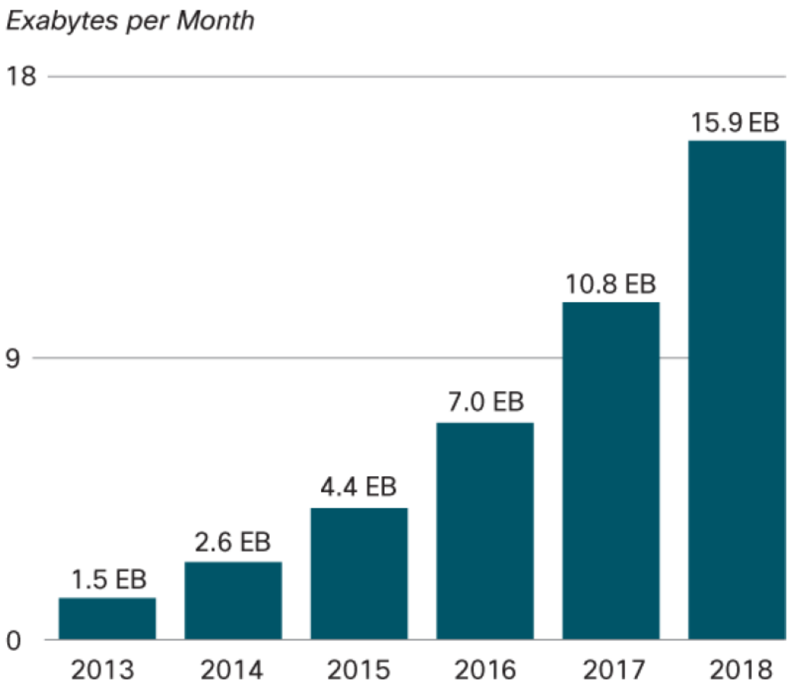
The above-mentioned circumstances fostered the interest

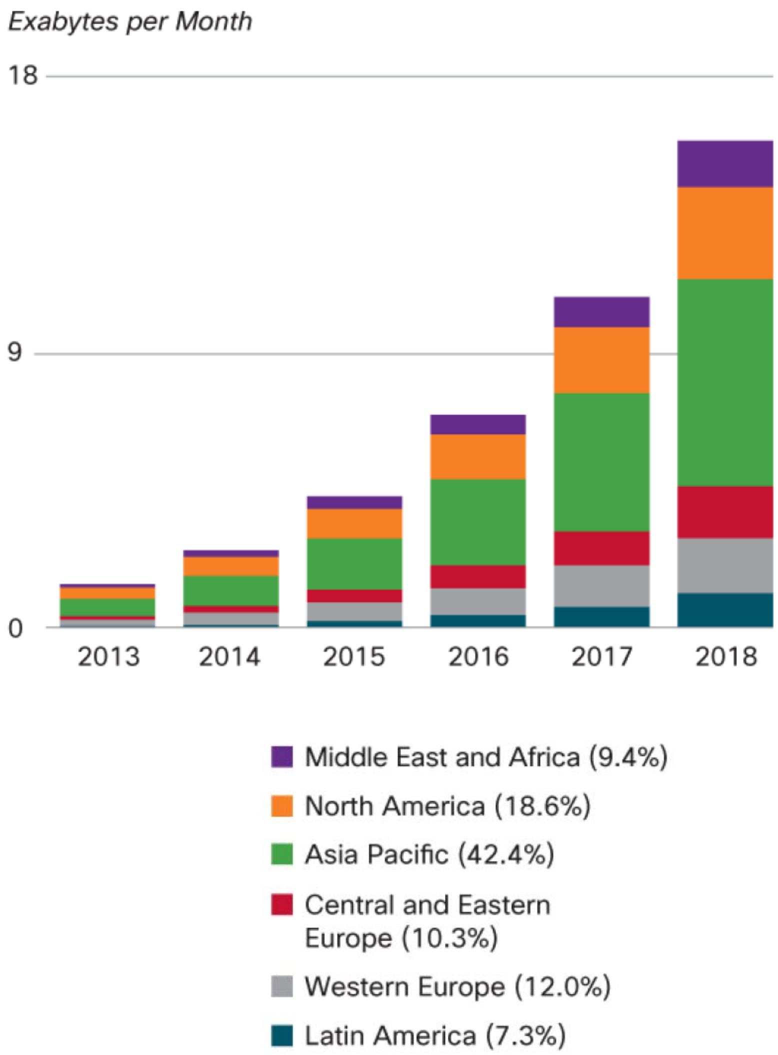
Future Data Traffic – numbers from the past

Region	Mobile Traffic Growth Examples
Korea	As reported by Korean regulator KCC, mobile data traffic on 2G, 3G, and 4G networks increased approximately 70% between 3Q 2012 and 3Q 2013.
China	Mobile data traffic of China's top 3 mobile operators grew 90% in 2012 and 72% from mid-2012 to mid-2013.
Japan	Mobile data traffic grew 92% in 2012 and 66% from 3Q 2012 to 3Q 2013, according to Japan's Ministry of Internal Affairs and Communications.
India	Bharti Airtel reported mobile data traffic growth of 112% between 3Q 2012 and 3Q 2013. Reliance Communications reported mobile data traffic growth of 116% between 3Q 2012 and 3Q 2013.
Australia	As reported by Australian regulator ACMA, mobile data traffic grew 47% from mid-2012 to mid-2013.
Italy	As reported by Italian regulator AGCOM, mobile traffic in Italy in 3Q13 was up 34% year-over-year.
France	As reported by French regulator ARCEP, mobile traffic in France was up 60% from 2Q 2013 to 2Q 2012.
Germany	As reported by German regulator BNA, mobile traffic in Germany grew 40% in 2012.
Sweden	As reported by Swedish regulator PTS, mobile traffic in Sweden grew 69 percent from mid-2012 to mid-2013.
Russia	Vimpelcom reported mobile data traffic growth of 106% from 3Q 2012 to 3Q 2013.
Other	Vodafone's year-over-year global mobile traffic growth was 60% from 1Q FY12 to 1Q FY13. Vodafone's European traffic grew 35% during fiscal year 2012–2013, up from 18% the previous fiscal year.

Source: „Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2013–2018", Feb. 2014,
http://www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/white_paper_c11-520862.html

Future Data Traffic – Forecast by Cisco





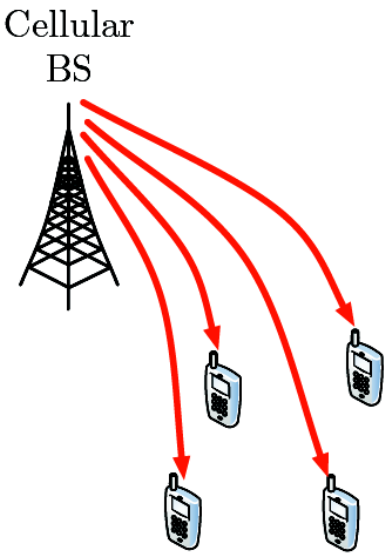
Challenge: Accomodate Data Overload
⇒ major investments
- radio access network (RAN)
- core infrastructures

Source: „Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2013–2018", Feb. 2014,
http://www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/white_paper_c11-520862.html

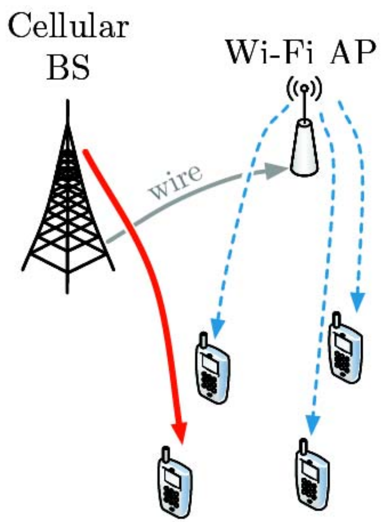
Data Offloading

The use of a **complementary wireless technology** to transfer data originally targeted to flow through the cellular network.

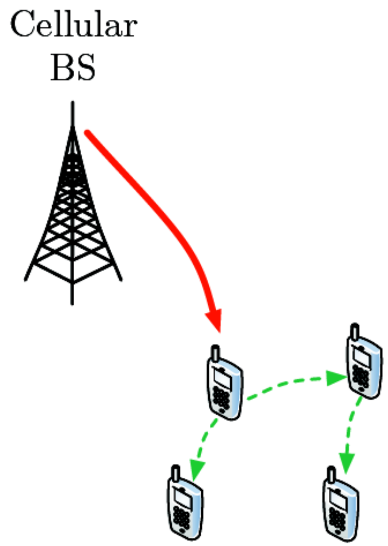
Infrastructure only



Access Point based offloading



Terminal-to-Terminal offloading



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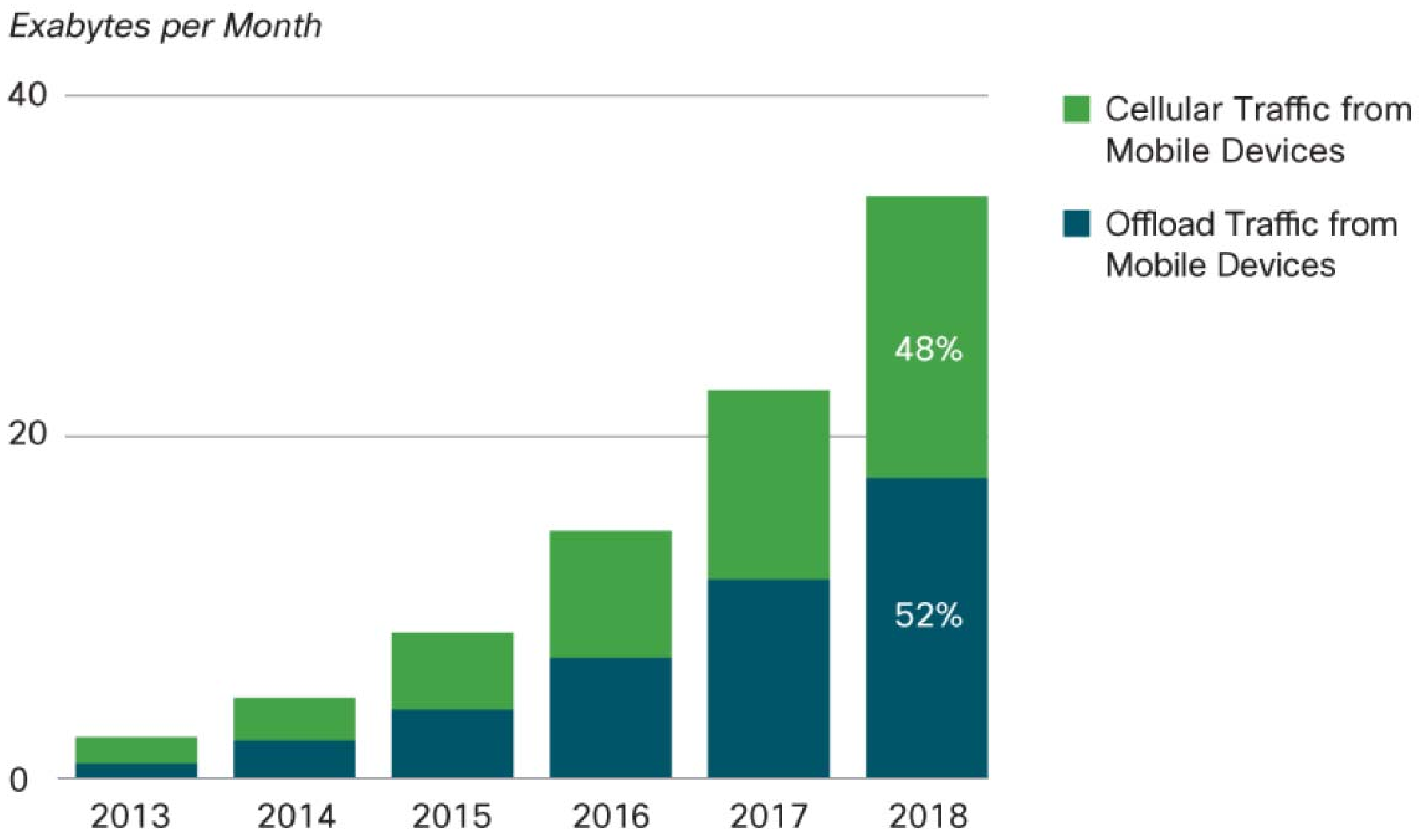
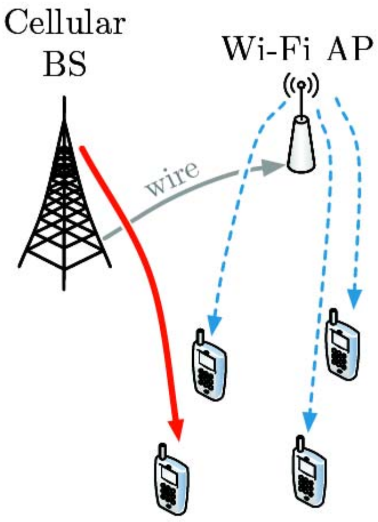


Source: „Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2013–2018", Feb. 2014, http://www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/white_paper_c11-520862.html

Data Offloading – Classification

	Access Point based offloading	Terminal-to-Terminal offloading
Non Delayed • hard delivery **delay constraint** by the application • e.g., interactive audio and video streams	**"Seamless integration"** • AP Deployment and Modeling • 3GPP Standardization • Transport Protocols	**"Tethering"** • Cooperative Distribution • Device to Device Capabilities Integration • cf. Tetra DMO • cf. LTE-Advance Standardization (ongoing)
Delayed 1. loose guarantees (some packets can be delayed, but content must reach user within limit) 2. truly delay-tolerant (without any delay guarantees)	**"Scheduling"** • Prediction-Based Offloading • Feasibility and AP Deployment **e.g., wait until next WiFi AP available**	**"Opportunistic Networks"** • Subset Selection • Architecture

Access Point based offloading



Source: „Rebecchi, F.; Dias de Amorim, M. ; Conan, V. ; Passarella, A. ; Bruno, R. ; Conti, M.: "Data Offloading Techniques in Cellular Networks: A Survey", 2014

- offloading today is **userdriven**
  - users explicitly enable the alternative access network
  - Smartphones already give priority by default to WiFi
- **Limitations**:
  - constrained mobility
  - lack of session continuity
- **Future:**
  - **tighter integration** of alternative access networks and their cellular infrastructure
  - partnerships between cellular and wireless providers,
    - common billing and accounting policies,
    - shared subscriber databases for authentication, authorization, accounting (AAA),
    - security provisioning
- **Approaches**:
  - **loose coupling**
    - networks are independent and interconnected => roaming
  - **tight coupling**
    - common core (vertical and horizontal handover, common AAA)

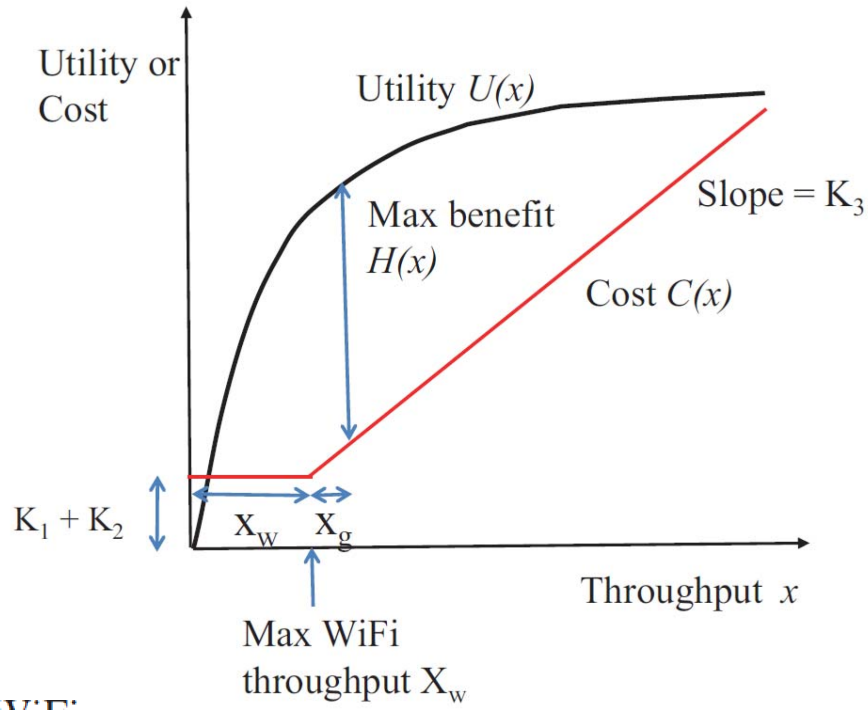
Access Point based offloading – Coupling Approaches / Standards

	Strategy	IPv4/v6	Dynamic	Direction	Offload
3GPP	ANDSF Only	Both	No	Operator	Access/Core
	SIPTO	Both	No	N/A	Core
	LIPA	Both	No	Operator	Access/Core
	IFOM	Both	Yes	Operator/UA	Access
IETF	DHCPv6	IPv6	UE inits	UA	Access/Core
	RFC 4191	IPv6	Yes	Operator	Access/Core
	RFC 4191 + IPv4	Both	Yes	Operator	Access

Source: „Rebecchi, F.; Dias de Amorim, M. ; Conan, V. ; Passarella, A. ; Bruno, R. ; Conti, M.: "Data Offloading Techniques in Cellular Networks: A Survey", 2014

- as of today, **no commercial deployments**
- **widespread adoption** is one of the keys to enable effective operator-driven offloading strategies

- **Utility** U(x) is a **function of throughput** x
  - how much the user values throughput
  - modeled as logarithmic function
- **cost function** C(x) that also depends on the throughput x on that link
- U(x) - C(x) is the **user's benefit**
  - should be maximized



Strategy 1

1) Use the maximum possible throughput on WiFi ($x_w = X_w$) at all points of time.
2) If the throughput on WiFi is not sufficient (i.e., $X_w < \frac{1}{K_3}$), use 3G only to fill in the slack (i.e., $x_g = \frac{1}{K_3} - X_w$), but no more. Thus, the 3G link is to be throttled unless the maximum throughput on 3G is already less than $\frac{1}{K_3} - X_w$.

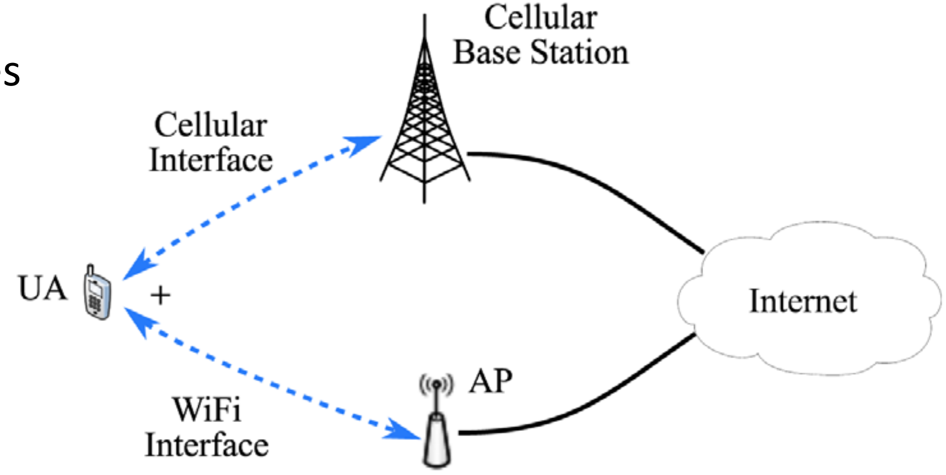
Challenges:
- **scheduling**
- **striping**
- **throttling**

for the different links.

Source: „X. Hou, P. Deshpande, and S. R. Das, "Moving bits from 3g to metroscale WiFi for vehicular network access: An integrated transport layer solution," in IEEE International Conference on Network Protocols (ICNP), Oct. 2011.

Access Point based offloading – Transport Protocols

- simultaneous use of multiple technologies
- **transport protocol** needs to cope with
  - seamless switch overs,
  - different simultaneous connections,
  - aggregation between multiple access technologies.



Source: „Rebecchi, F.; Dias de Amorim, M. ; Conan, V. ; Passarella, A. ; Bruno, R. ; Conti, M.: "Data Offloading Techniques in Cellular Networks: A Survey", 2014

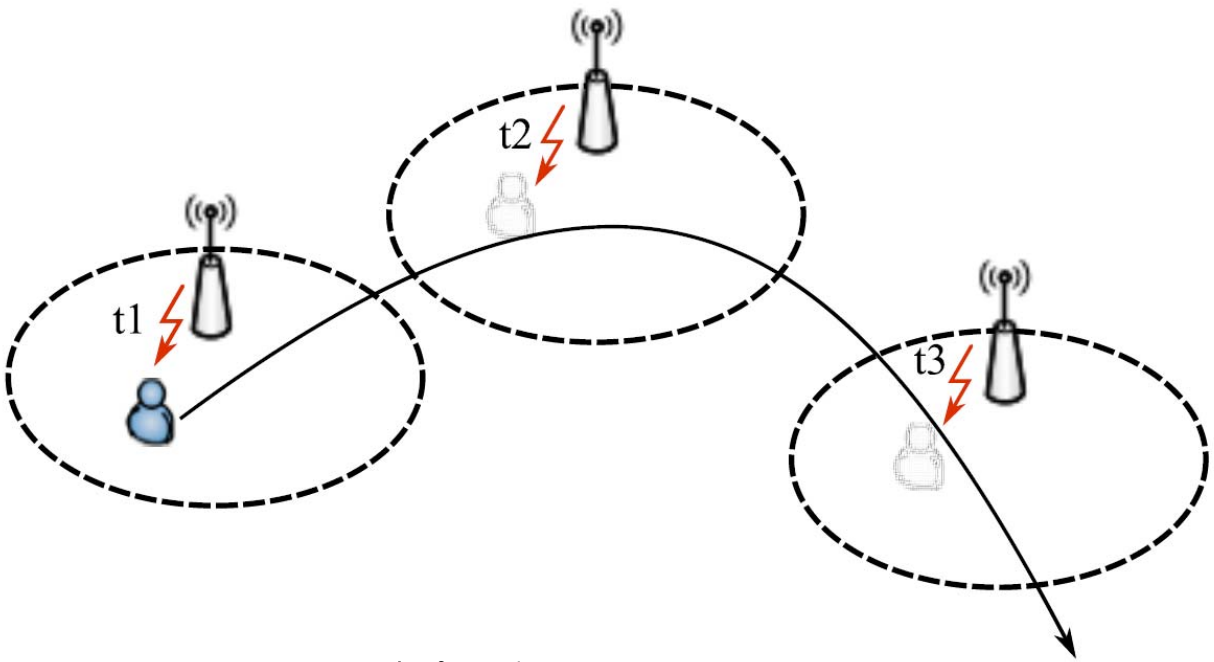
Selected Approaches:

- **SCTP-based** (Stream Control Transmission Protocol, RFC4960)
  - SCTP can bind multiple IP addresses at each communication
  - adds striping and throttling capabilities to the standard SCTP
  - real world experiments claim a 65-80% cellular data reduction

Source: „X. Hou, P. Deshpande, and S. R. Das, "Moving bits from 3g to metroscale WiFi for vehicular network access: An integrated transport layer solution," in IEEE International Conference on Network Protocols (ICNP), Oct. 2011.

- **MPTCP** (MultiPath Transmission Control Protocol, RFC6824)
  - no additional requirements on the network
  - entirely implemented at end-hosts
  - several working implementations, e.g., Android

Delayed Access Point based offloading



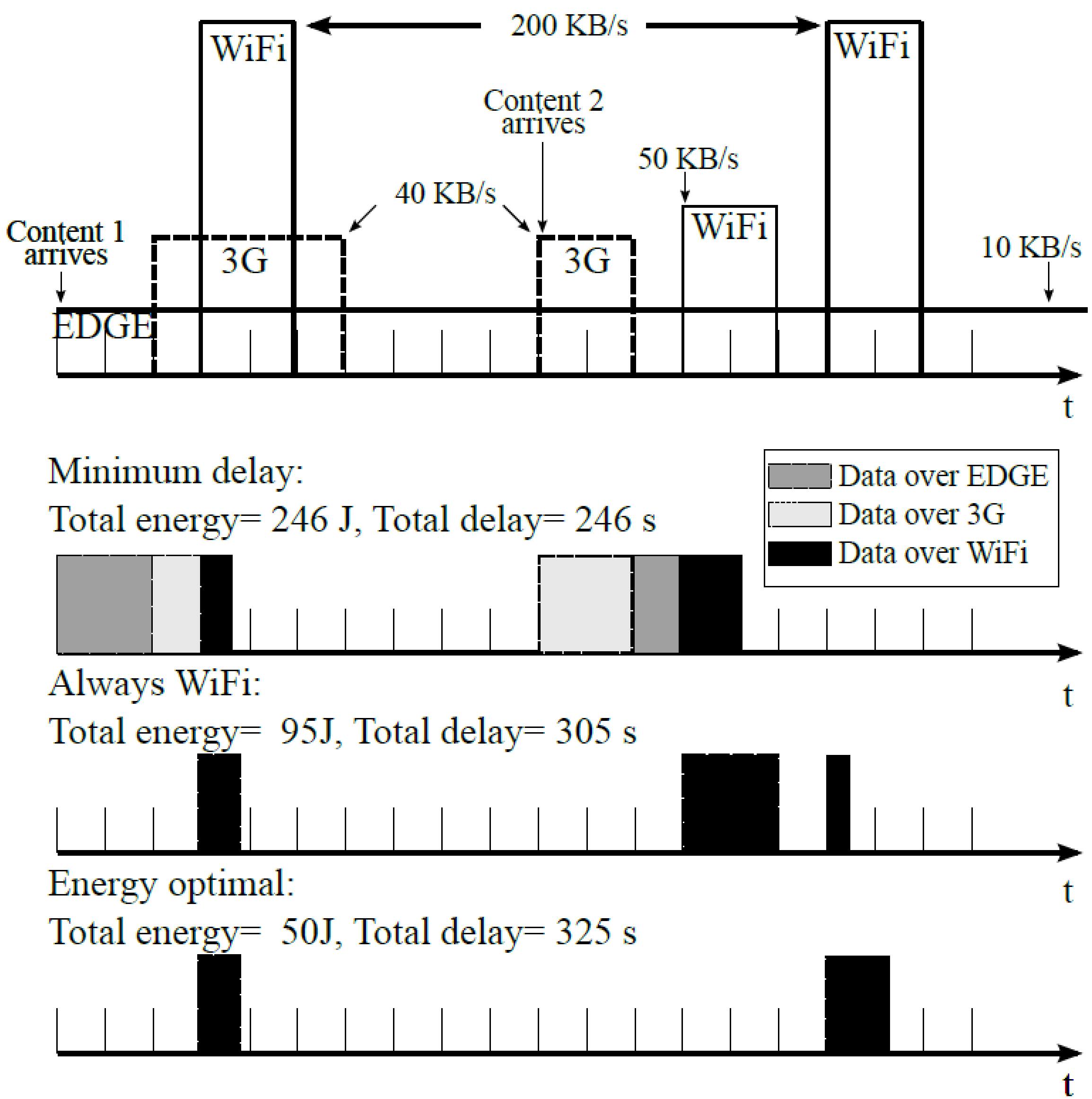
Source: „Rebecchi, F.; Dias de Amorim, M. ; Conan, V. ; Passarella, A. ; Bruno, R. ; Conti, M.: "Data Offloading Techniques in Cellular Networks: A Survey", 2014

- movement creates **contact opportunities** with fixed APs

  ⇒ **offloading capacity** of the network

- predicting the **future offloading potential** through past behaviors
  - mobility,
  - contacts with APs,
  - throughput.

Delayed Access Point based offloading – Example "SALSA – Framework"



Offloading Strategy

Minimum delay
minimizes the total delay, selecting always the channel with the fastest data rate

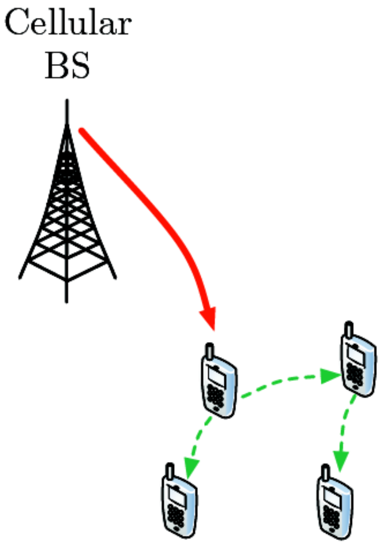
Always WiFi
uses only WiFi APs, regardless of their data rate

Energy optimal
minimizes the energy consumption, using always the most energy efficient channel

Source: M.-R. Ra, J. Paek, A. B. Sharma, R. Govindan, M. H. Krieger, and M. J. Neely, "Energy-delay tradeoffs in smartphone applications," in International conference on Mobile systems, applications, and services- MobiSys,, 2010.

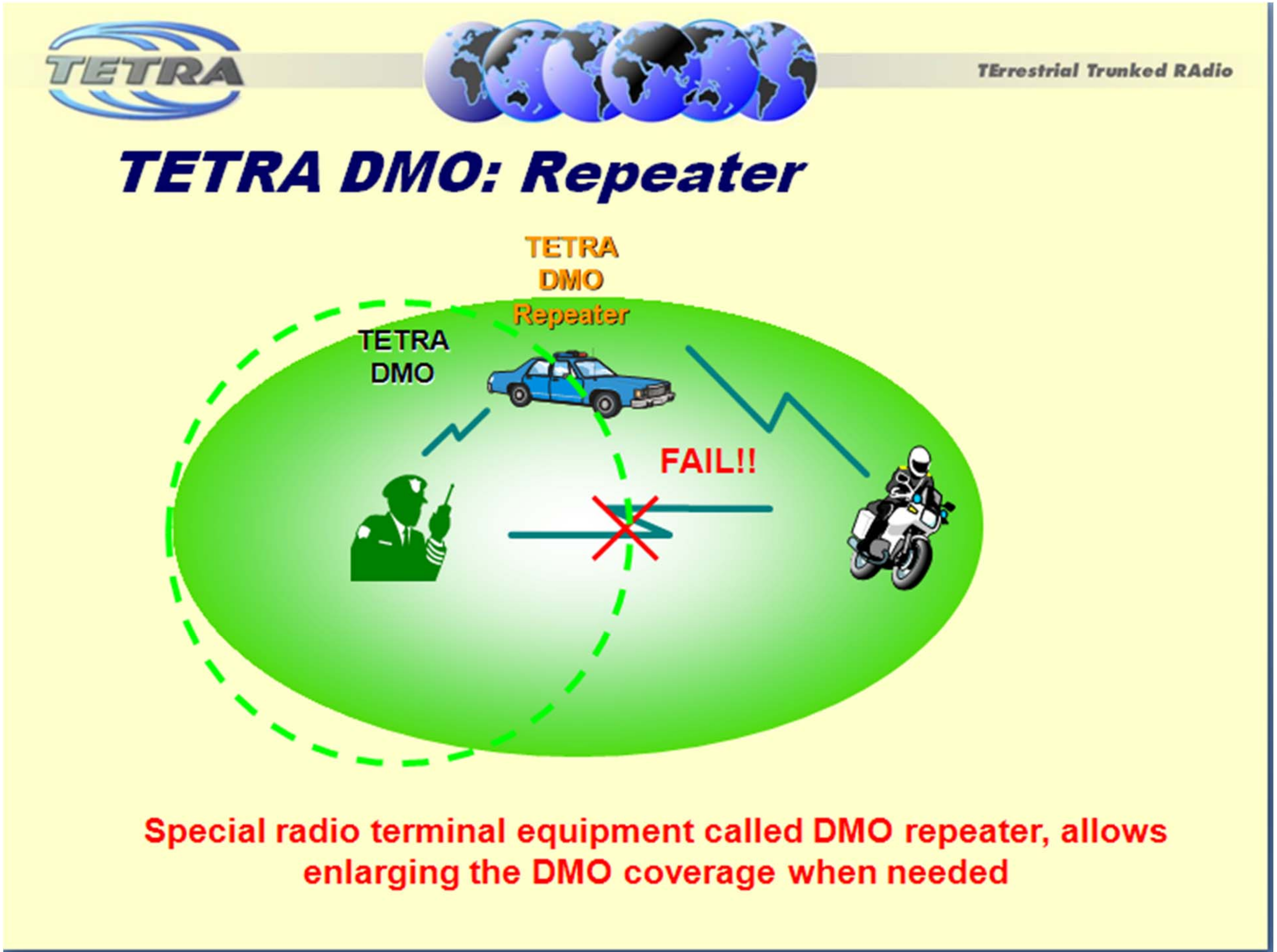
T2T Offloading – Capability Integration

- end-users **discover** each other in proximity
- nodes communicate
  - dedicated resources
  - shared uplink cellular channel
- D2D **communications are triggered by the cellular network**
  - continuous network management and control
  - can be used for load balancing purposes

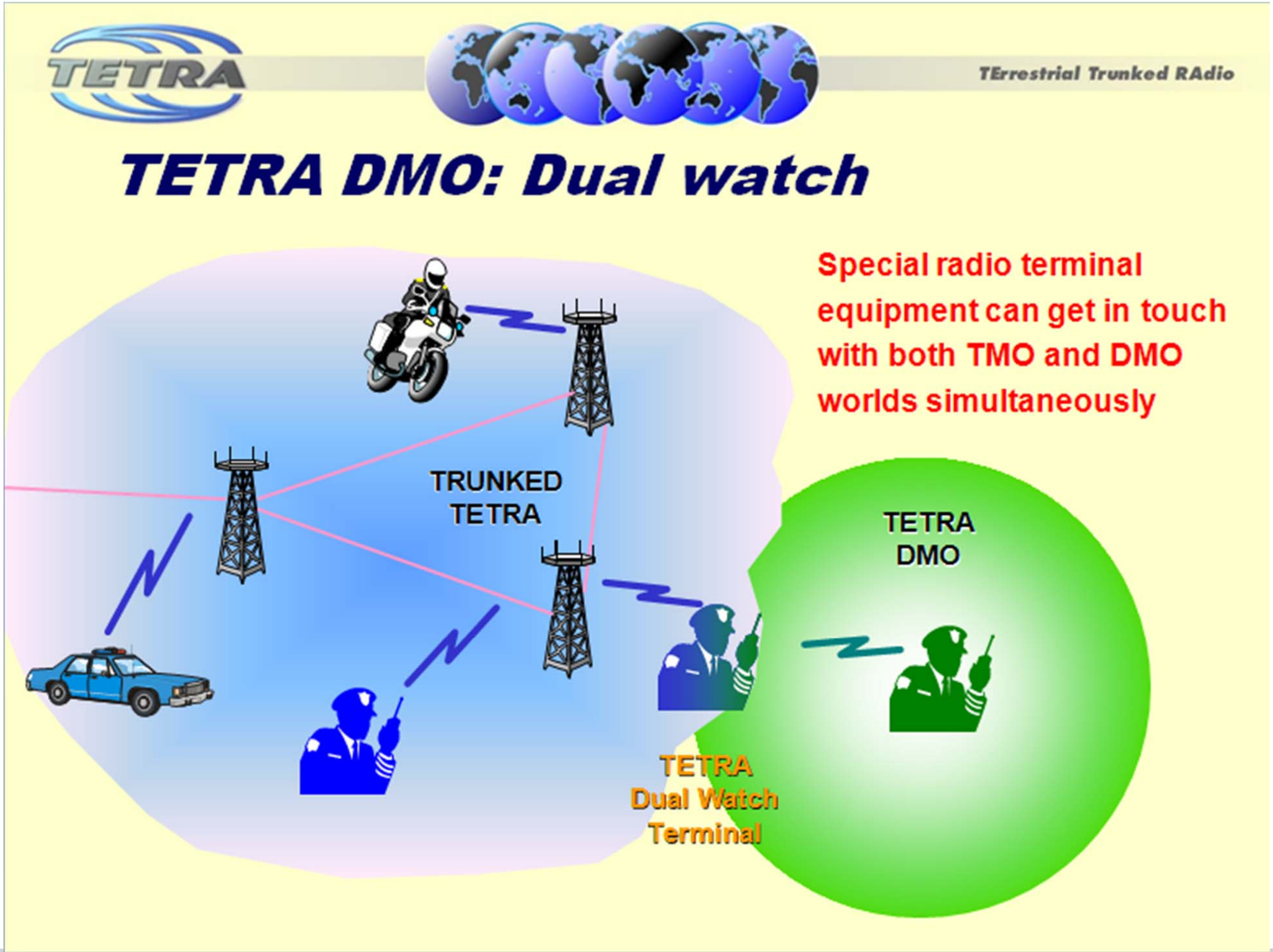


Source: „Rebecchi, F.; Dias de Amorim, M. ; Conan, V. ; Passarella, A. ; Bruno, R. ; Conti, M.: “Data Offloading Techniques in Cellular Networks: A Survey”, 2014

- cf. Tetra DMO
- cf. LTE-Advance Standardization (ongoing)

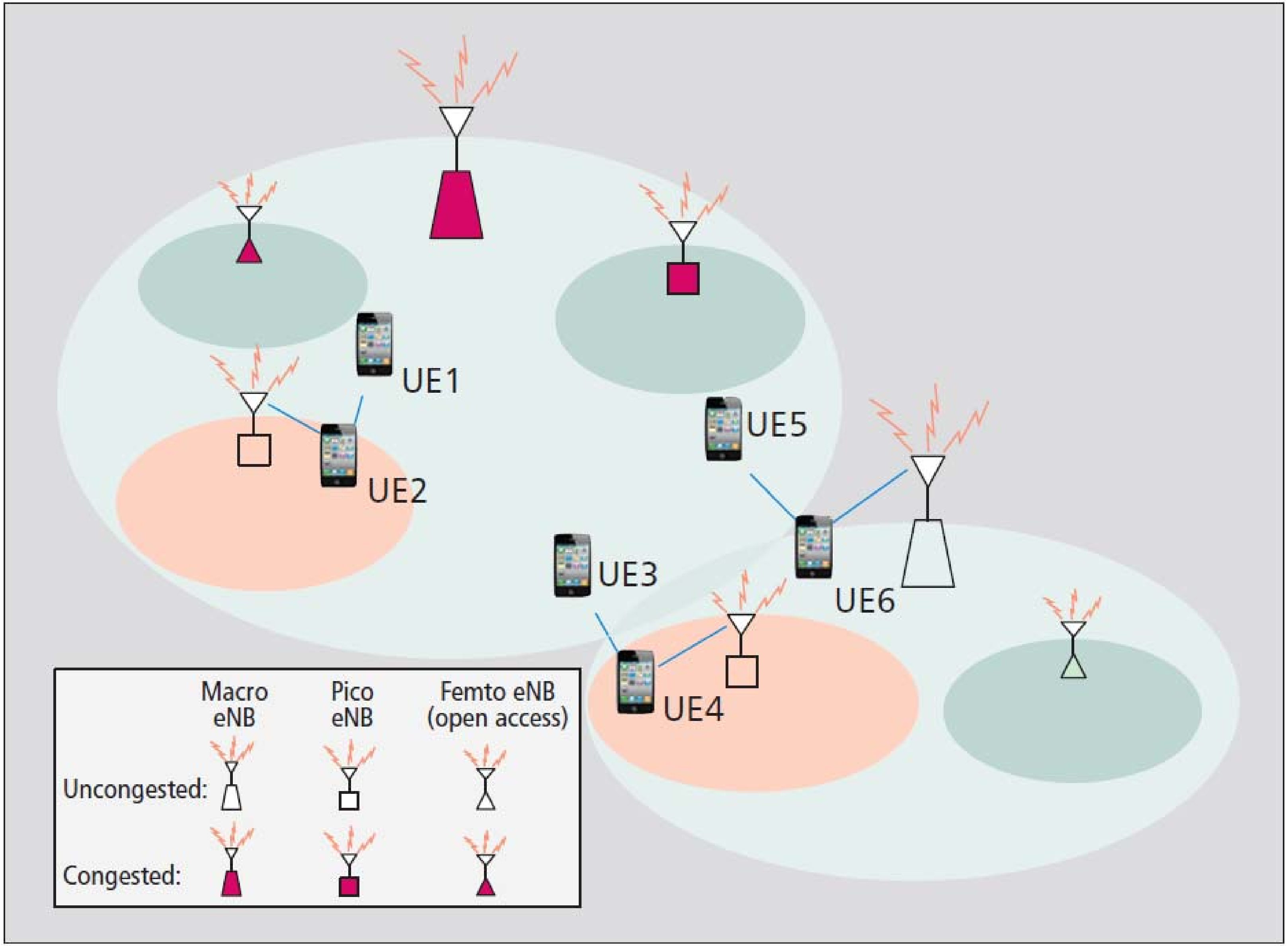


Source: www.tetramou.com
Francesco Pasquali - The power of TETRA - Direct Mode Operation



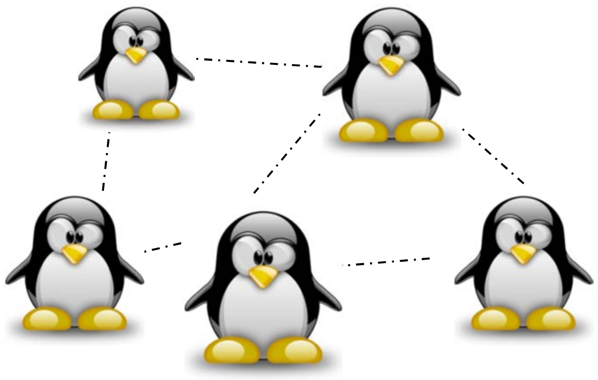
Source: www.tetramou.com
Francesco Pasquali - The power of TETRA - Direct Mode Operation

T2T Offloading – Load Balancing in LTE-Advanced Networks

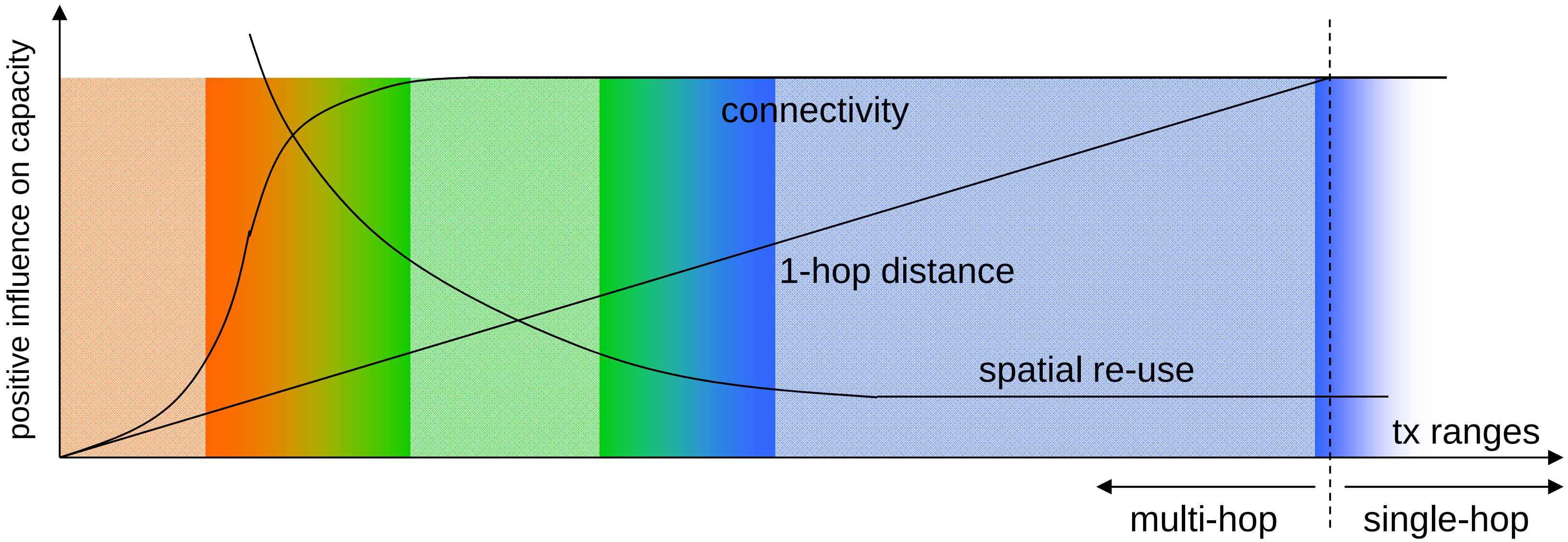


Source: Jiajia Liu,Kawamoto, Y. ; Nishiyama, H. ; Kato, N. ; Kadowaki, N.: Device-to-device communications achieve efficient load balancing in LTE-advanced networks, IEEE Wireless Communications, Volume:21, Issue: 2, Apr. 2014-

- networks as graphs
  - k-connectivity
  - number of partitions

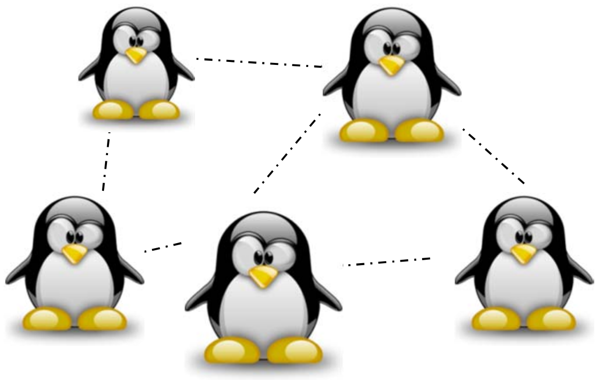


Tux-Illustrations from http://tux.crystalxp.net/



Opportunistic Networks (aka Delay Tolerant Networks)

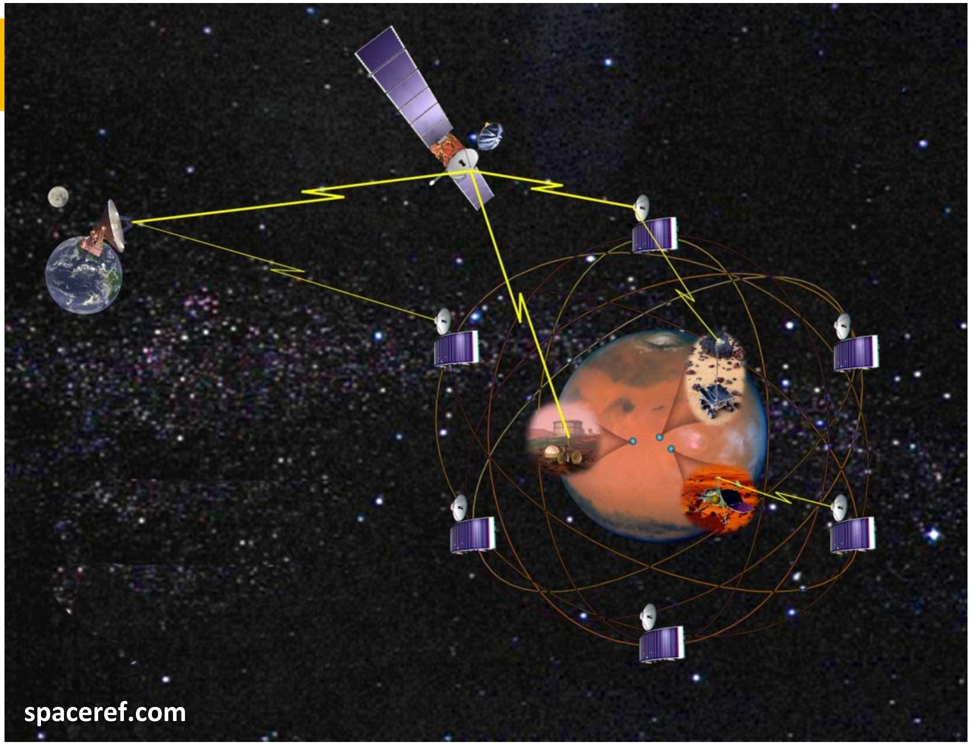
- Opportunistic Networks
  - k-connectivity << 1 (averaged over time)
  - number of partitions >> 2
- Concept
  - **Store Carry Forward**
- Scenarios
  - Rural Areas
  - Underwater-Networks
  - Catastrophees (IAA = I am alive)
  - Wildlife-Monitoring
  - …



atlas-elektronik.com

(Original) Delay Tolerant Networks

With increased understanding of **how to communicate with an orbiting satellite**, the concept of contact points began to become a key focus in the research in space communication. The key idea behind a contact point is that there is only a **set duration of time where both the source and the receiver points are able to communicate** with one another. Source: wikipedia.org



Literature:

- Burleigh, S.; Hooke, A. ; Torgerson, L. ; Fall, K. ; Cerf, V. ; Durst, B. ; Scott, K. ; Weiss, H.: “Delay-Tolerant Networking: An Approach to Interplanetary Internet”, IEEE Communications Magazine, Vol.:41 , Issue:6, Jun. 2003, pp. 128 – 136.
- RFC 5325 - 5327: ”Licklider Transmission Protocol”

.. the **Licklider Transmission Protocol (LTP)** designed to provide **retransmission-based reliability** over links characterized by **extremely long message round-trip times** (RTTs) and/or **frequent interruptions** in connectivity. Since communication across interplanetary space is the most prominent example of this sort of environment, LTP is principally aimed at **supporting "long-haul" reliable transmission in interplanetary space**, ...
This document is a product of the **Delay Tolerant Networking Research Group** ... Source: RFC 5325

Joseph Carl Robnett Licklider

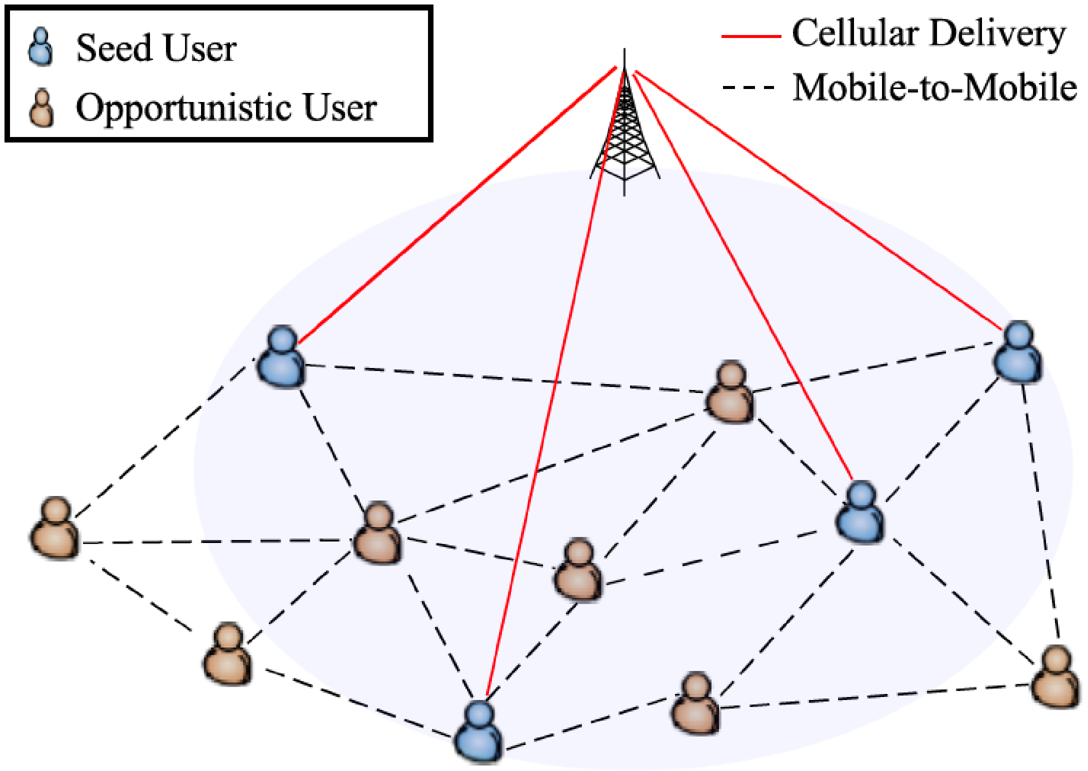
LTP is named in honor of the American computer scientist **Joseph Carl Robnett Licklider**.

- March 11, 1915 – June 26, 1990
- In 1957 he became a Vice President at **BBN**, where he bought the first production PDP-1 computer and conducted the first **public demonstration of time-sharing**.
- In August 1962 at BBN he formulated the earliest ideas of a global computer network, in a series of memos discussing the "**Intergalactic Computer Network**" concept.
- In October 1962 appointed as head of the Information Processing Techniques Office (IPTO) at **ARPA**, the United States Department of Defense Advanced Research Projects Agency.
- In April 1963 he sent a **memo** to his colleagues in outlining the **early challenges** presented in **establishing a time-sharing network of computers** with the software of the era.
- His vision led to **ARPANet**, the precursor of today's Internet.
- The idea of the "**Intergalactic Computer Network**" contained almost **everything that the Internet is today, including cloud computing**.

Source: wikipedia.org

Delayed T2T Offloading – Basic Concept

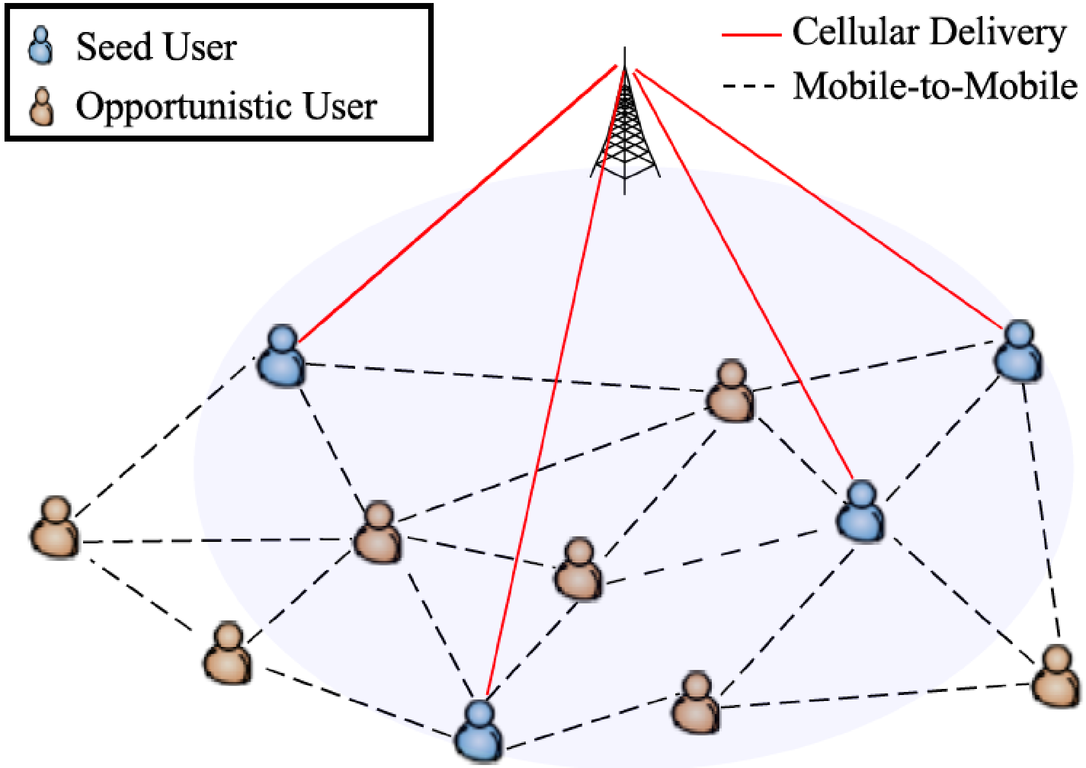
- the **opportunistic approach** only allows the diffusion of data with **loose delivery constraints**
- **popular content** is ideally supplied only to a **small fraction** of selected users



Source: „Rebecchi, F.; Dias de Amorim, M. ; Conan, V. ; Passarella, A. ; Bruno, R. ; Conti, M.: "Data Offloading Techniques in Cellular Networks: A Survey", 2014

- any **forwarding or data dissemination scheme** proposed for opportunistic networks can be used to **disseminate the content among mobile nodes**
  - epidemic forwarding (similar to flooding)
  - using statistical and mobility characteristics of nodes to select seed users

Delayed T2T Offloading – Challenge: Subset Selection



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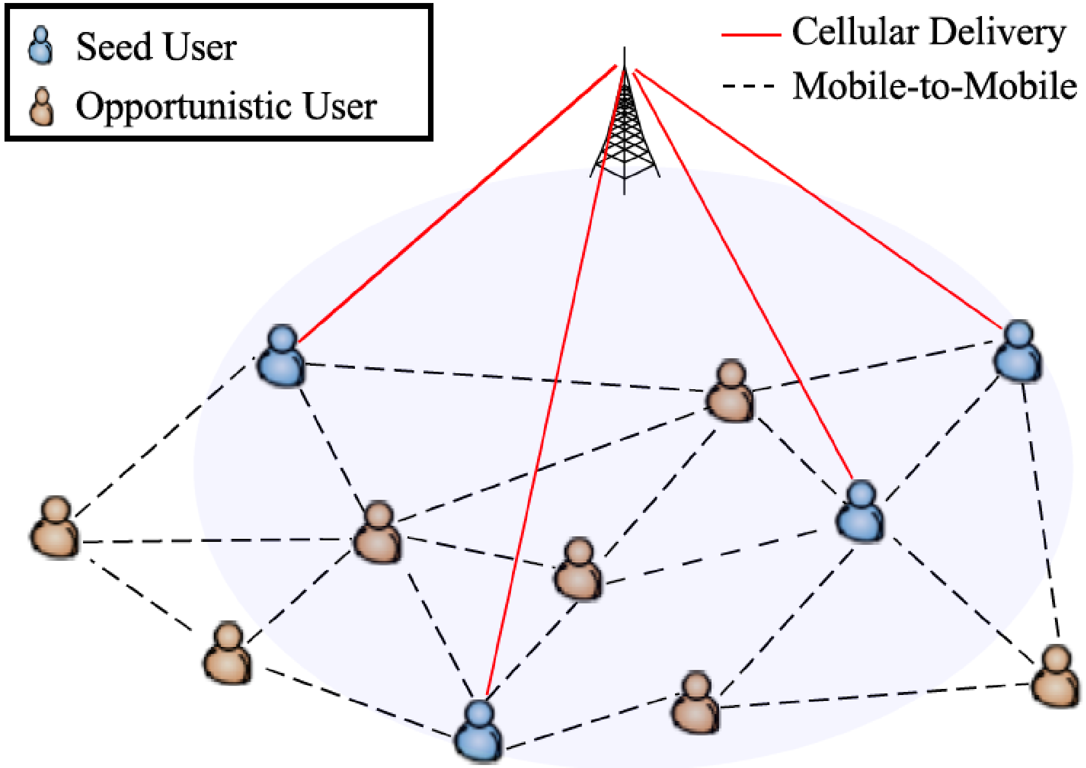
- selecting **high potential nodes as seeds** of the dissemination process influences the **performance** of the offloading strategy
- some users may infect a larger number of nodes, resulting in **lesser late retransmissions**
- **social interactions** among users and their **mobility patterns** to figure out which nodes have the best features
- **control channel**, binding the end-nodes to a central entity, is usually required in order to transfer context information

Delayed T2T Offloading – Challenge: Mechanisms (1)

- what type of **traffic to offload** and how, **defining communication protocols** etc.



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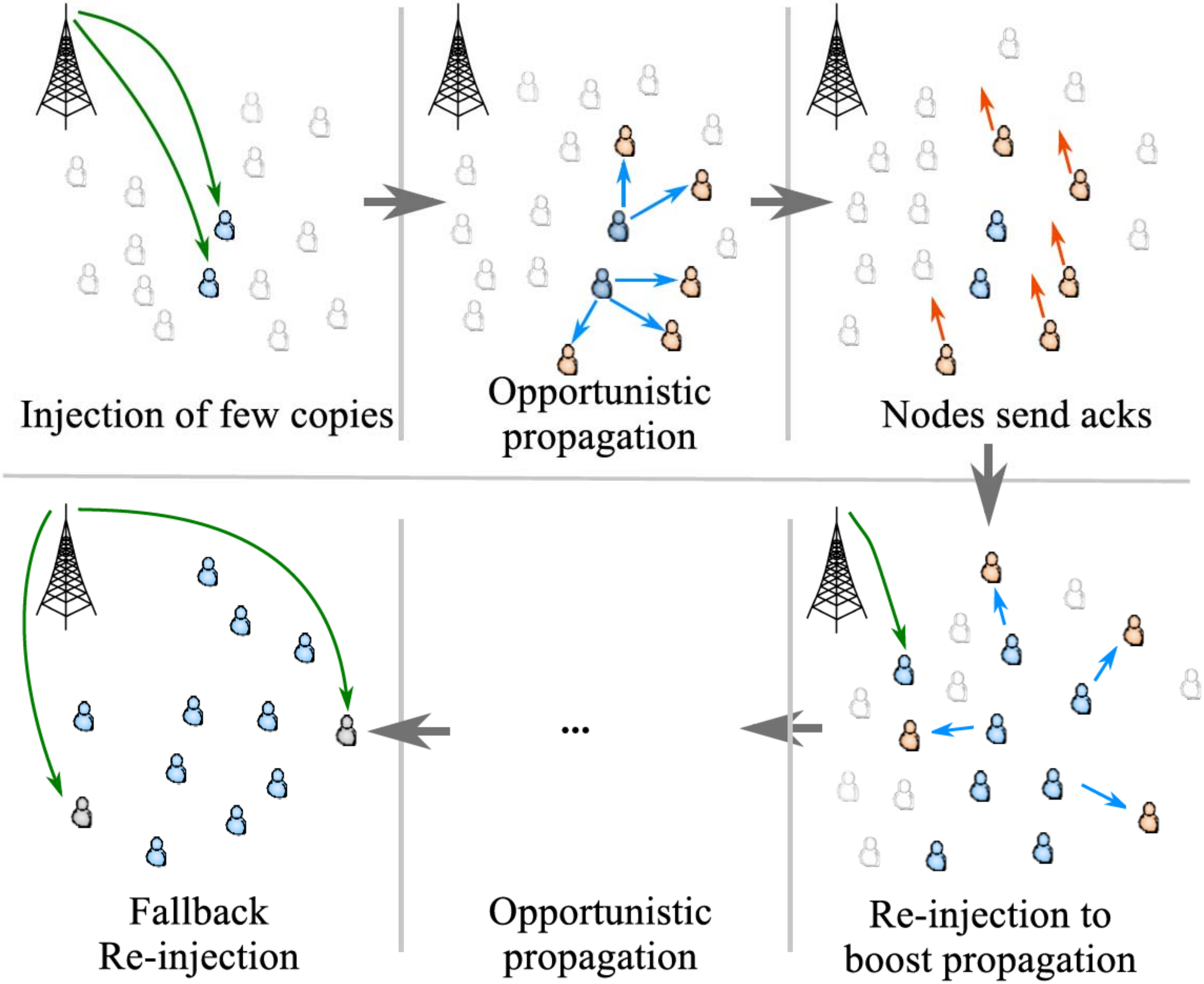
Example 1:

- protocol initially **attempts to deliver messages through opportunistic communications**
- **switches to the infrastructure** network only when the **probability of delivering** the message within the deadline becomes unlikely

cf.: C. Mayer and O. Waldhorst, "Offloading infrastructure using delay tolerant networks and assurance of delivery," in IFIP Wireless Days, 2011



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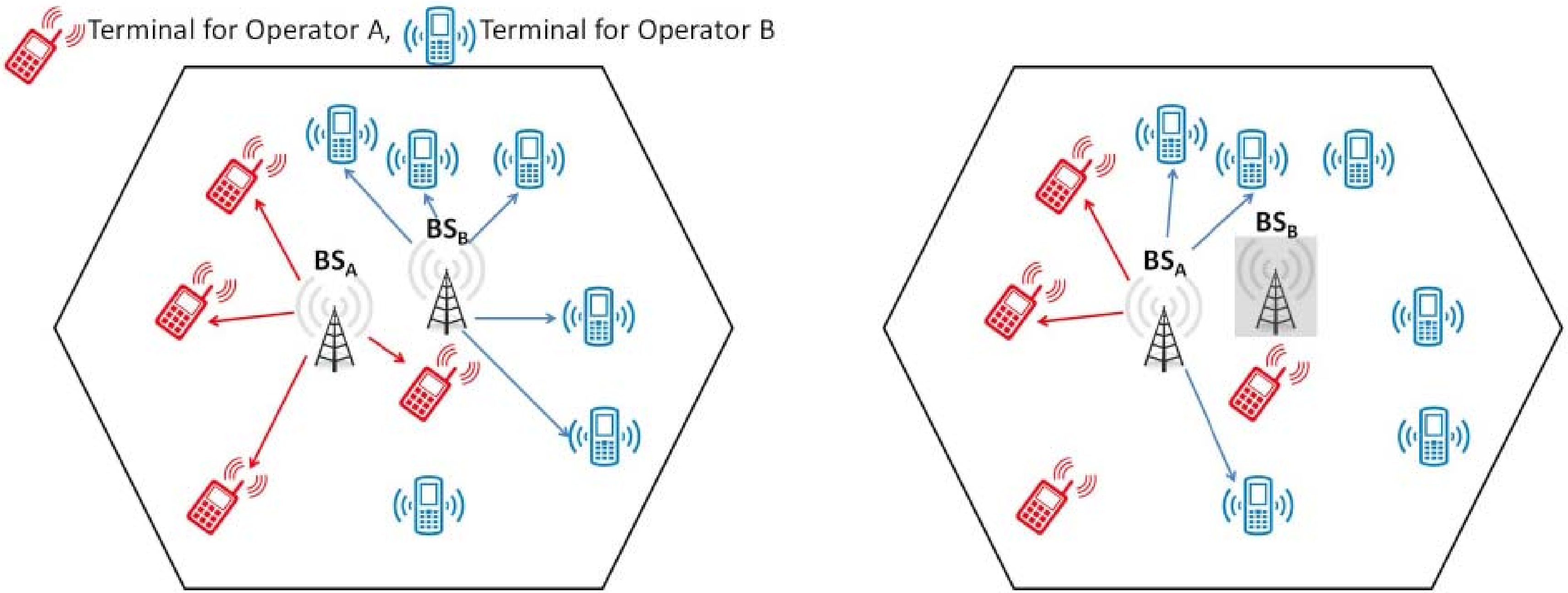
cf.: J. Whitbeck, Y. Lopez, J. Leguay, V. Conan, and M. D. de Amorim, "Push-and-track: Saving infrastructure bandwidth through opportunistic forwarding," Pervasive and Mobile Computing, vol. 8, no. 5, pp. 682–697, Oct. 2012.

Alternatives to Offloading

- addition of **small-size base station**.
  - operators need additional base stations
- addition of **femtocells**.
  - analogous to AP-based offloading, but same access technology of the macro-cell
  - Challenge: interference management
- **multicasting/broadcasting** data inside the cell.
  - assumption: many users in spatial proximity ask for the same data
  - requires modifications in the cellular architecture
  - user experience different radio link conditions => reduces the effectiveness
- integration of **cognitive radio** mechanisms.
  - dynamically detect unused spectrum and share it without harmful interference
- **proactive pushing** of popular content on devices.
  - store popular data in a cache located at the edge of network
  - predict users’ next requests and pre-fetch the corresponding content

Base-Station Sharing



Source: Bingjie Leng; Mansourifard, P. ; Krishnamachari, B.: „Microeconomic analysis of base-station sharing in green cellular networks", Proc. of IEEE Infocom, 2014, pp. 1132-1140.