Wireless Multi-hop Ad Hoc Networks

From WBANs to Large Scale Topologies

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University Sorbonne Paris Nord

Habilitation à Diriger des Recherches (HDR)

Outline

- **Career Summary**
- **Context of my research**
- **Wireless Body Area Networks**
- **Large Scale Wireless Sensor Networks**
- **Vehicular ad hoc Networks**
- **Conclusion**

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Career timeline

- **1999-2000** : Research Master, University of Versailles, France
- **2000-2003** : Network development engineer, Hipercom Project, INRIA, France
- **2003-2006** : PhD in Computer Science, Hipercom Project, INRIA, France
- **2006-2007** : Postdoctoral position at ENST (currently Télécom ParisTech)
- **Since 2007** : Associate professor at university Sorbonne Paris Nord (L2TI)

Administrative and teaching responsibilities

Administrative responsibilities

- **2013-2016** : Director of AIR, supGalilée Engineering School, USPN
- **2011-2013** : Head of AIR2, supGalilée Engineering School, USPN

Teaching responsibilities

- **IP next generation networks**: M2 3IR (networking), ING3 (computer science)
- **Wireless and mobile networking**: M2 3IR (networking)
- **IP computer networking**: M1 3IR (networking), ING2 (computer science)
- **Linux operating system**: M1 3IR (networking)

Scientific outreach

- **Project evaluator**: The ANR, The ANRT-MESR
- **Co-chair of the steering committee**: MobileHealth, Since 2014
- **General Co-chair**: MobileHealth'11, MobileHealth'12, MobileHealth'13, eHealth track CCNC'16
- **Editorial advisory board**: eHealth book, IGI Global, 2014

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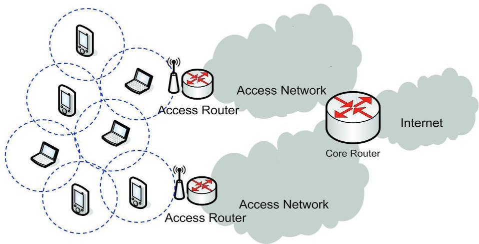
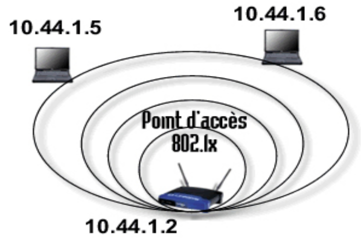
Mobile Ad hoc Networks: MANETs

- **Architecture**

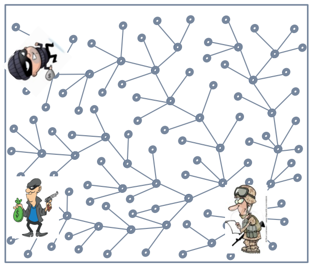




➡ Extension of access point networks architecture (IEEE 802.1x).

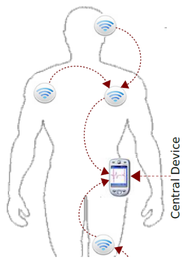
- **Applications**

Military



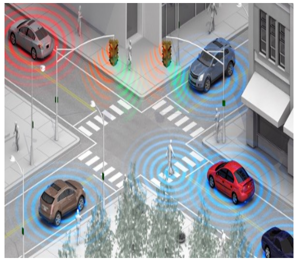
Intrusion detection

Disasters



Health monitoring

Agricultural Monitoring



Traffic Safety

First experience
INRIA Rocquencourt

- **Hiperlan driver (European standard - ETSI)**
  - Implementation, deployment and tests
- **OLSR protocol (IETF standard – RFC 3626)**
  - Definition of the protocol
  - Active participation to standardisation efforts at IETF
  - Implementation, deployment and tests
- **Raising issues (ENST - R2M Project)**
  - Protocols not well adapted to application architectures
    - Deployment architecture : VANETs, WSNs, … etc.
  - Protocols not well adapted to nodes' characteristics
    - Mobility of the nodes

Application driven solutions

University Sorbonne Paris Nord

Wireless Body Area Networks (WBANs)

- Intra and Inter-WBANs routing
- Off-WBAN scheduling
- Intra-WBAN MAC cooperation

Large scale wireless sensor networks (WSNs)

- Mobile sink routing
- Duty-Cycling

Vehicular ad hoc networks (VANETs)

- Geocast routing in VANETs
- Swarm intelligence routing in UAVs

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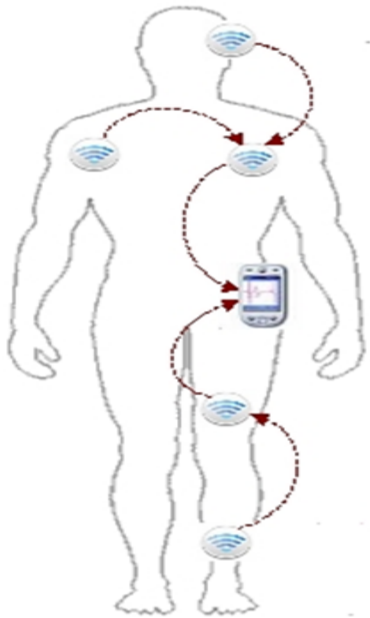
Intra-WBAN routing

- **Very small scale deployment**
- Short transmission range

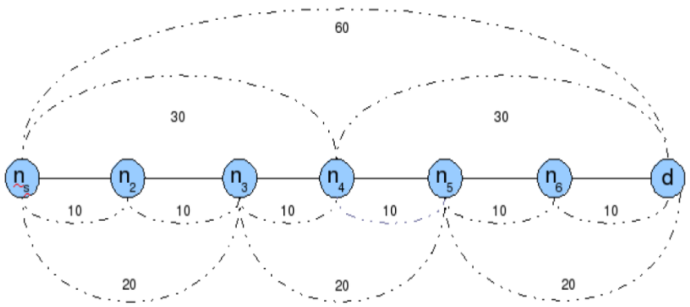
- **Transceiver's power consumption**
- Almost equal in Tx and Rx in low ranges
- Two contradictory approaches
  - High power single hop transmission (body coverage) [1]
  - Lower power multi-hop transmissions [2]
- **Is multi-hop routing necessary & Energy efficient?**



1. B. Latre, I. Moerman, B. Dhoedt, P. Demeester: "Networking in wireless body area networks", 5th FTW PHD Symposium, 2004
2. Q. Wang, M. Hempstead, W. Yang: "A Realistic Power Consumption Model for Wireless Sensor Network Devices", IEEE SECON 2006

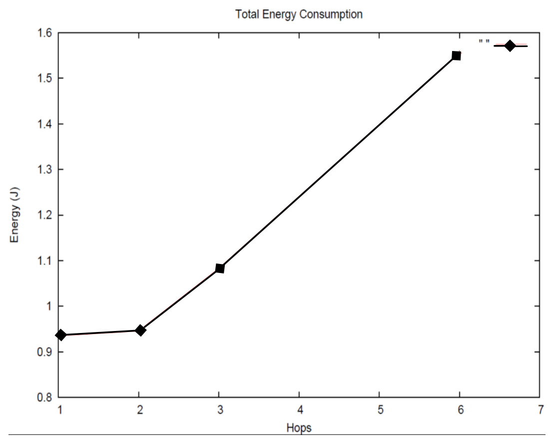
Intra-WBAN routing
Single vs. Multi-hop Power Consumption Analysis

- **Crossbow CC1000 transceiver power consumption values**

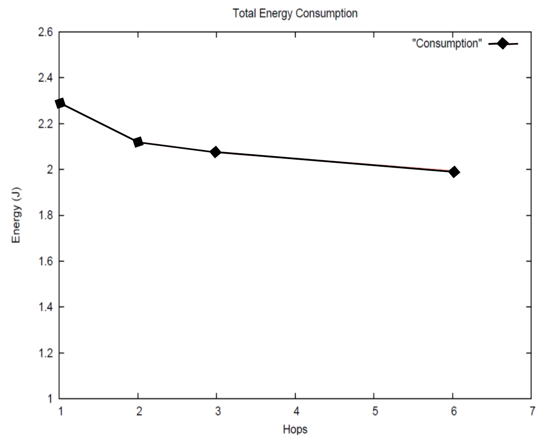


Tx Power (dBm)	Power Consumed (mW)	Rx/Idle Listening (mW)	Tx Range (meters)
05	76.2	30	60
-07	32.4	30	30
-14	27.9	30	20
-20	25.8	30	10

$P_{TR} < P_{REC}$



Transceiver in active state only for Transmission (Tx)



Transceiver always in active state (Tx/Rx/Idle)

Intra-WBAN routing
Main conclusions

- **Deliberate reduction of transmission power is not energy efficient for WBANs**

- **No need to sophisticated routing mechanisms**
  - However, signal absorption by human body, body posture !
  - In case of problem simple 2 hop routing is sufficient [1]
  - Later recommended by IEEE 802.15.6 working group [2]

Algorithm 1 : Beacon processing at node$_i$

Recv(**Beacon**$_{new}$,**node**$_j$)
    // New Beacon received
    if (sequence_no($Beacon_{new}$) >
      sequence_no($Beacon_{last}$))
        next_hop$_{coordinator}$=node$_j$
        rebroadcast(Beacon$_{new}$)
    //multiple copies or old beacon received
    else if (sequence_no($Beacon_{new}$) <=
      sequence_no($Beacon_{last}$))
        discard($Beacon_{new}$)

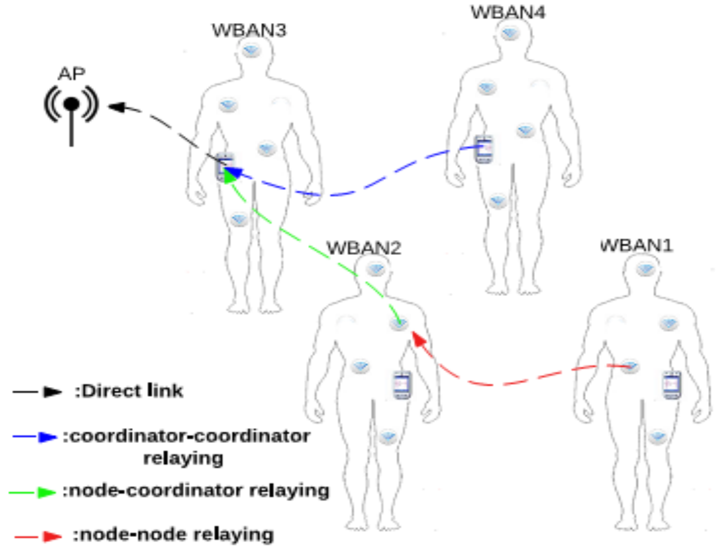
1. Y. Faheem, S. Booudjit : "WBANs: Information Dissemination Analysis", IEEE HealthINF 2010.
2. Ieee 802.15.6 wpan task group 6 (tg6) - body area networks. www.ieee802.org/15/pub/tg6.html, 2012.

Inter-WBANs routing

- **Issues**
  - WBAN far from AP: Link quality
  - WBAN coordinator's battery depletion

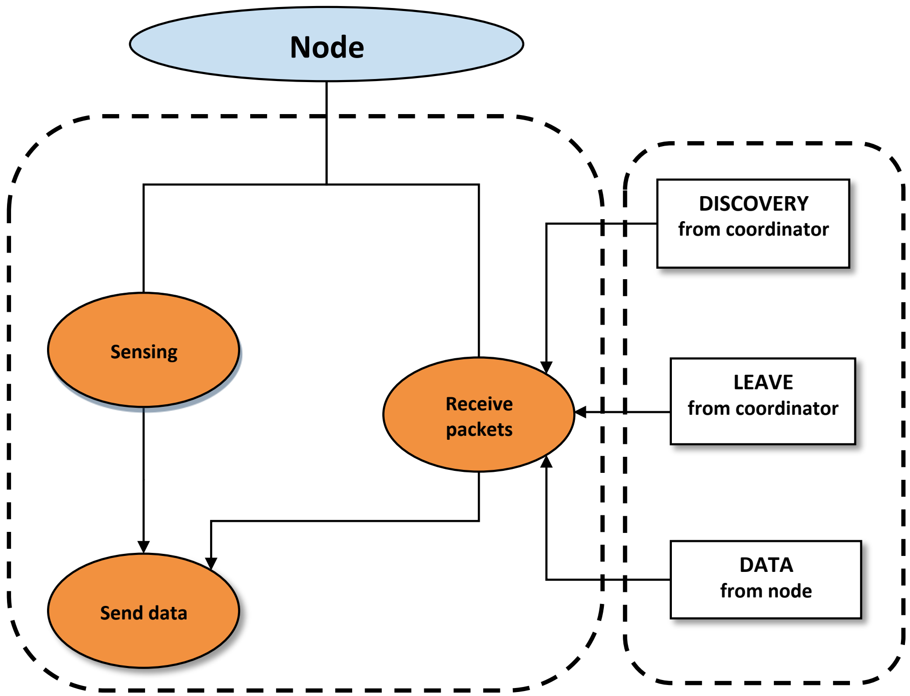
- **Solution in case of time-sensitive data ?**
  - **NetBAN** : routing solution based on energy threshold technique [1,2]

- **Goal :**
  - Inter-WBAN relaying
  - Network lifetime enhancement

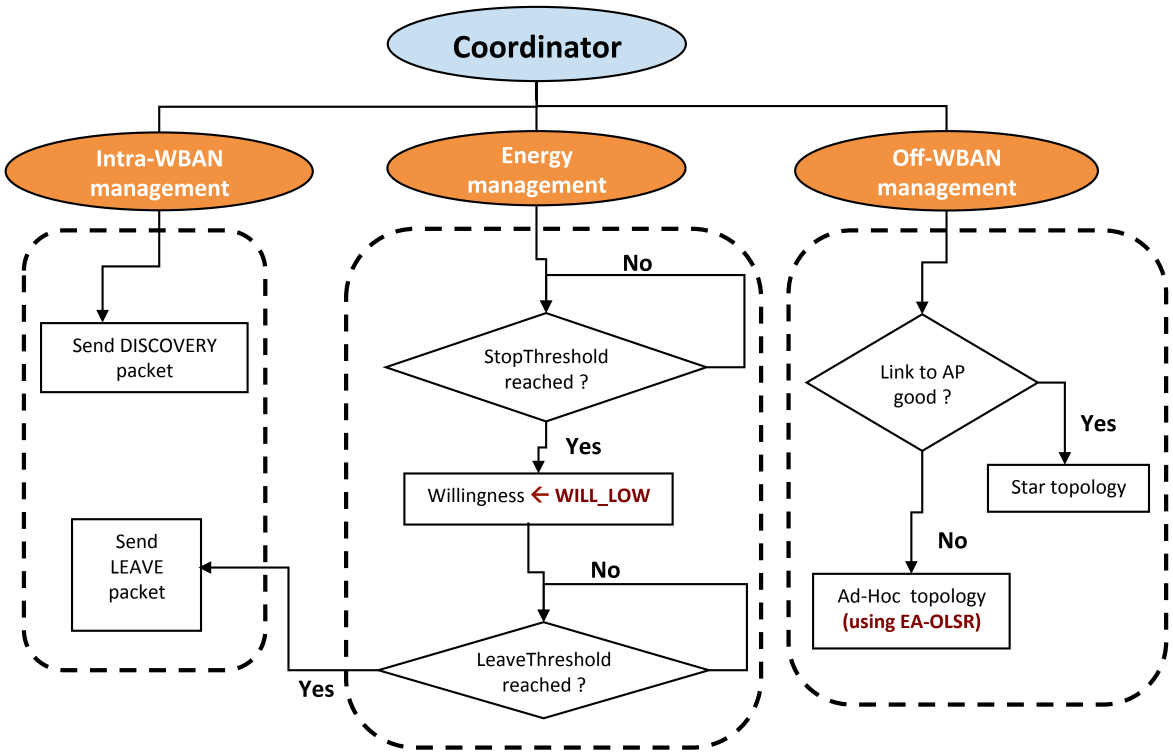


1. A. Manirabona, S. Boudjit, L. Chaari: "NetBAN, a concept of network of BANs for cooperative communication: energy awareness routing solution", IJAHUC, Inderscience, 2018.
2. A. Manirabona, S. Boudjit, L.Chaari: "Energy aware routing protocol for inter WBANs cooperative communication", IEEE ISNCC 2015.

NetBAN routing solution
Node principle



NetBAN routing solution
Coordinator principle



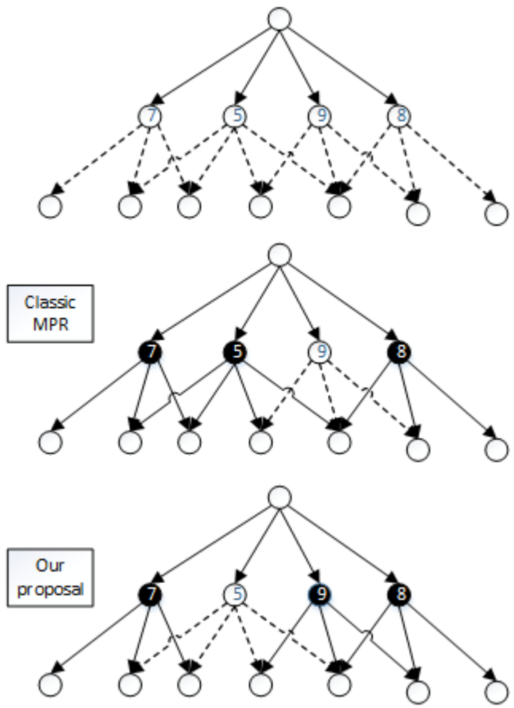
NetBAN routing solution
EA-OLSR

- **EA-OLSR (Energy Aware - OLSR)**
  - OLSR elects a node with many neighbors as MPR
  - EA-OLSR privileges a node with many neighbors and highest RLT (Residual Life Time)

$$RLT_i(t) = \frac{RE_i(t)}{RE_i(t-1) - RE_i(t)}$$

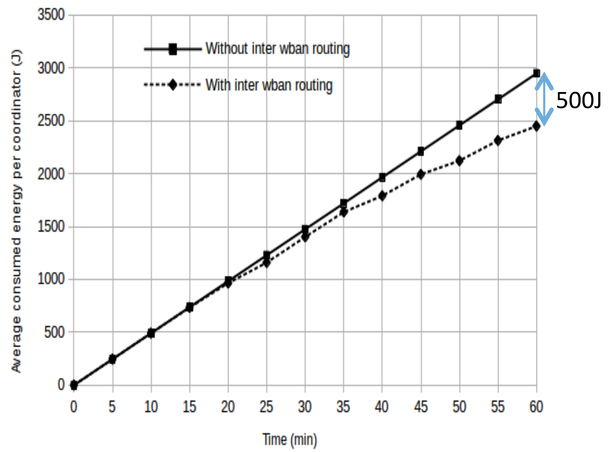
With RE = Residual Energy

  - OLSR chooses routes with few hops
  - EA-OLSR chooses routes with highest RLT

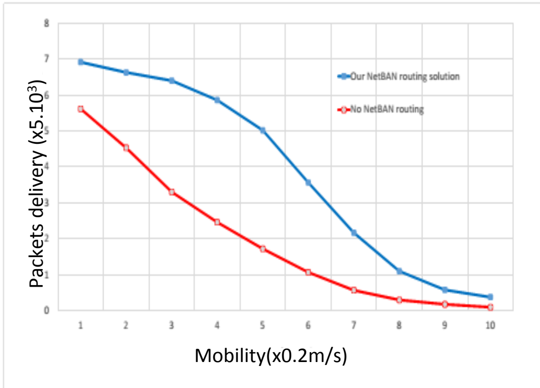


1, 2, 3, … : Node's RLT

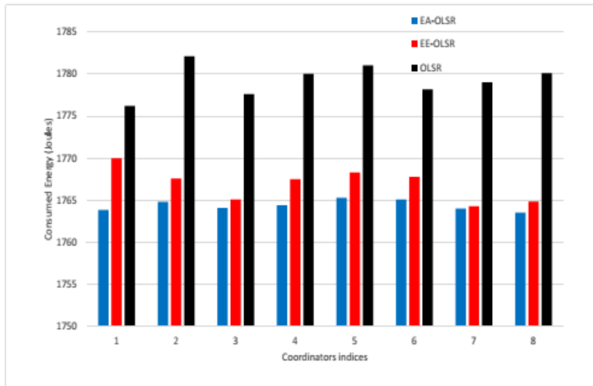
NetBAN routing solution
Performance of the protocol



- ≈ energy gain without mobility: 498.97 J = 12.224 min
- With mobility (1m/s) a gain of 20 min (30% in NLT)



- Without NetBAN, high sensitivity to the mobility
- With NetBAN, decrease of performance from 1m/s



- OLSR variants comparison: EA-OLSR, OLSR, EE-OLSR (De Rango et al., 08)[1]

1. F. De Rango, M. Fotino, and S. Marano: "EE-OLSR: Energy efficient olsr routing protocol for mobile ad-hoc networks", IEEE MILCOM 2008.

Intra-WBAN MAC cooperation

Mac-in-Mac Relaying

Motivation

- Energy optimization with MAC-in-MAC encapsulation (2-hop topology)
- ***body-frame-size*** (255 bytes + 9 bytes) too long for physiological data !

→ **Except for audio/video content**

Idea

- Resizing MAC format
- Merging frames before relaying [1]

Condition for merging

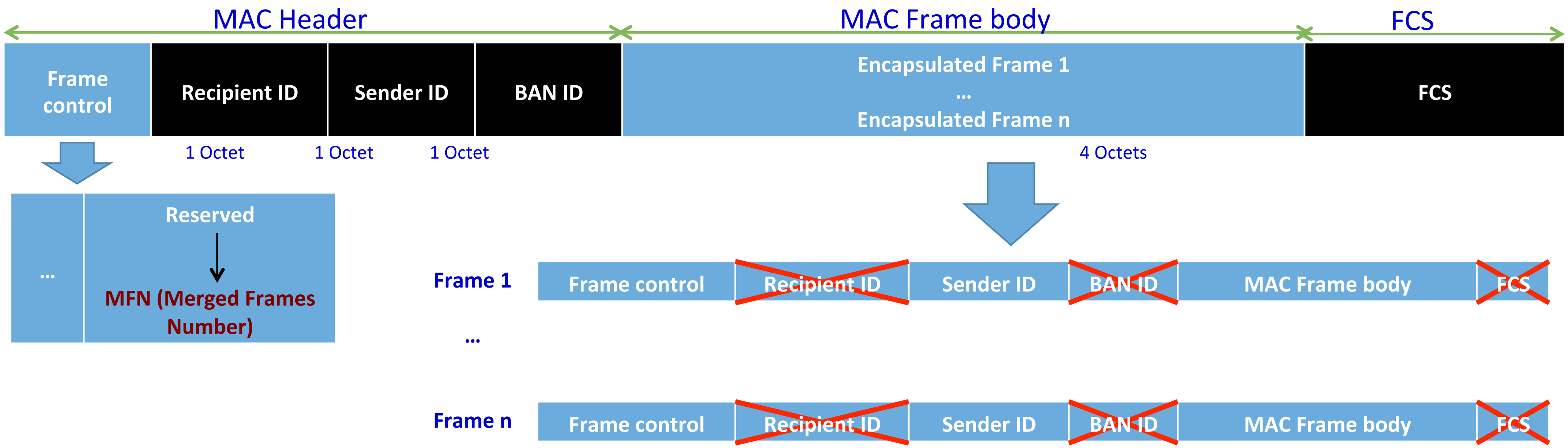
- ***frameType*** ≠ **EM** and Resulting frame size < ***body-frame-size***

1. A. Manirabona, S. Boudjit, L.Chaari: "Decode and Merge Cooperative MAC Protocol for intra-WBAN communication", IEEE Healthcom 2014.

Intra-WBAN MAC cooperation

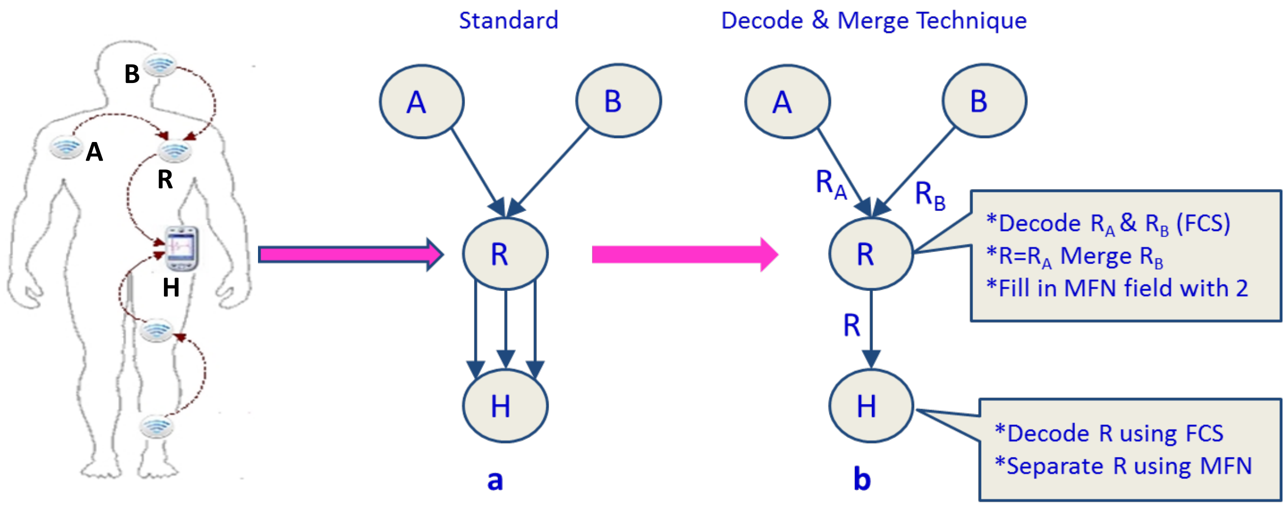
Principles

- Encapsulating frame: Reserved →MFN: Merged Frames Number
- Encapsulated frame: Remove Recipient ID, BAN ID, FCS
- Interleaving data



Intra-WBAN MAC cooperation

Principles



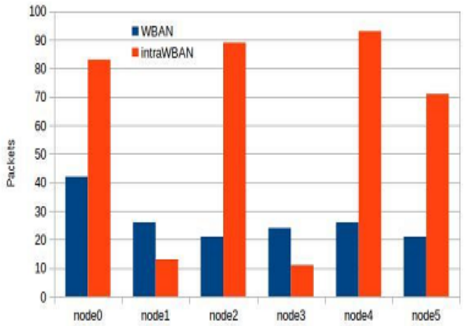
Example: m=3, n=8

- R1=01001100
- R2=10101010
- R3=11110000

→ R=011101011001110100010000

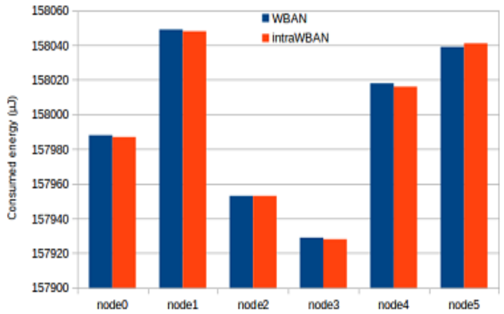
Intra-WBAN MAC cooperation

Simulations with Castalia: LTE – WIMAX - WIFI



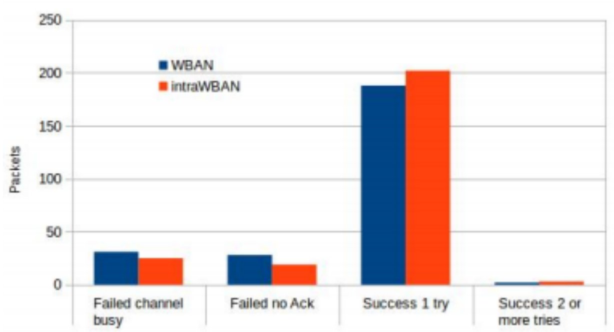
Packets delivery despite interference

- **Increase of packet delivery ratio even in interference conditions**



Consumed energy

- **Energy consumption slightly decreases despite of the increase packets delivery**



Failure and success transmission

- **Decrease of the number of transmission tries and failure due to channel busy or no ACK**

off-WBAN Scheduling

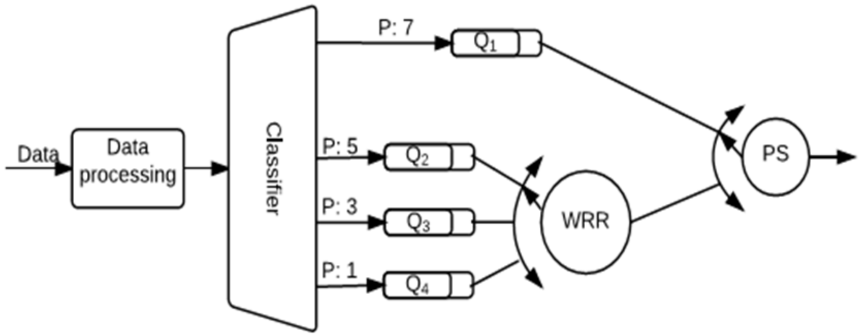
IEEE 802.15.6 Intra-WBAN Std (sensor to coordinator)	Off-WBAN Mapping (coordinator to next network)
$W_k^i = \begin{cases} W_0^i & when\ k = 0 \\ W_{k-1}^i & when\ k\ is\ odd, 1 \leq k \leq m \\ \min(2W_{k-1}^i, W_{max}^i) & when\ k\ is\ even, 2 \leq k \leq m \end{cases}$	$P_i = \begin{cases} \frac{UP_i}{2} \times 2 + 1, & when\ UP_i \geq 5 \\ \frac{UP_i - 2}{2} \times 2 + 1, & when\ UP_i < 5 \end{cases}$
k: number of retries, **m**: maximum number of retries, backoff counter **[1,W_k^i]**	emergency **EM**, medical data **MD**, Audio-video **AV** and non-medical data **nMD**

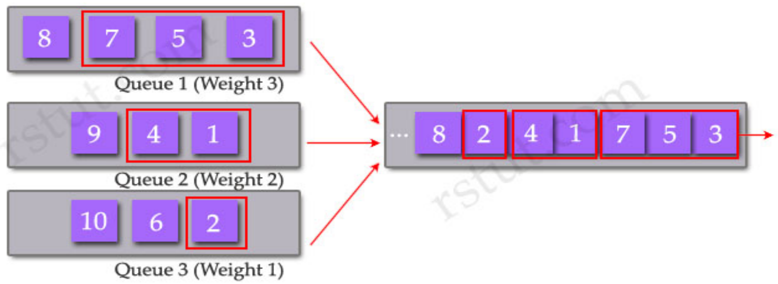
UP	Traffic	P	Traffic
0	Background traffic (BK)	1	nMD
1	Best Effort (BE)		
2	Excellent Effort (EE)		
3	Video (VI)	3	AV
4	Voice (VO)		
5	Medical Data (MD)	5	MD
6	High priority MD	7	EM
7	Emergency or Medical implant event report (EM)		

off-WBAN Scheduling
Scheduling model

Modules of the model:

PWRR: the system model includes **WRR** and the priority scheduling **(PS**)





- **Data input with UP (0-7)**
- **Data output with P (7, 5, 3, 1)=(EM, MD, AV, nMD)**
- **Advantages:**
  - **EM** flows keep priority in **PS**
  - **A**ll other flows benefit from non-preemptive **PS**

- **WRR: RR** with coefficients affected to each queue
  - Preserve lower priority queues from starvation
- **PWRR:** WRR whose coefficients are flows priorities

off-WBAN Scheduling

Scheduling model

Queue theory of M/G/1 system, n priorities, Poisson process flows arrivals with rate λ_i (i=1, …, n)

Stage 1: Priority Scheduling (PS)

System stability: $\sum_{i=1}^{n} \rho < 1$ with $\rho_i = \frac{\lambda_i}{\mu_i}$ and n number of queues

with λ_i, μ_i: arrival rate and service rate parameters of traffic class I

$E(D_i) = E(W_i) + 1/\mu_i$

By Pollatczek Khintchine formula and Little's law our system is modeled by:

$$\rightarrow E(W_i) = \frac{1}{2}\sum_{j=1}^{n}\frac{\rho_j}{\mu_j} / (1 - \sum_{j=1}^{i-1}\rho_j)(1 - \sum_{j=1}^{i}\rho_j)$$

Stage 2: WRR+PS

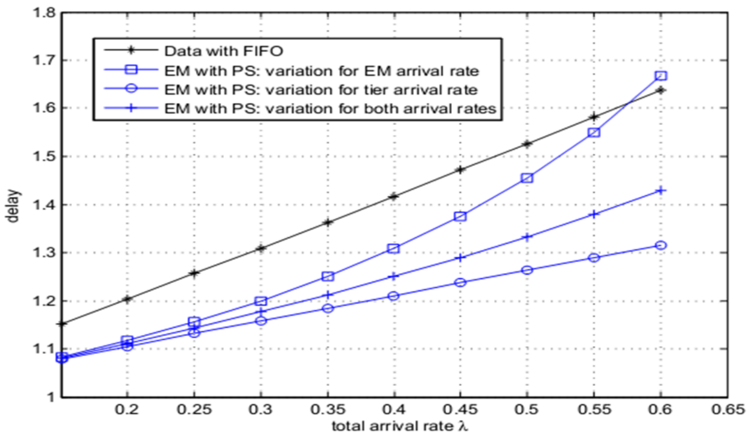
Given that the data traffic class i waits for $1 - \varphi_i$ unit of time and the probability B_{em} of EM to be on service (output in PS), we finally get:

$$\rightarrow E(W_i) = \frac{\frac{1}{2}\sum_{j=1}^{n}\frac{\rho_j}{\mu_j}}{\left(1-\sum_{j=1}^{i-1}\rho_j\right)\left(1-\sum_{j=1}^{i}\rho_j\right)}(1 - \varphi_i) + \frac{\frac{1}{2}\sum_{j=1}^{n}\frac{\rho_j}{\mu_j}}{(1-\rho_1)(1-\sum_{j=1}^{2}\rho_j)}B_{em}$$

$$E(D_i) = E(W_i) + \frac{1}{\mu_i}$$

off-WBAN Scheduling

Scheduling model



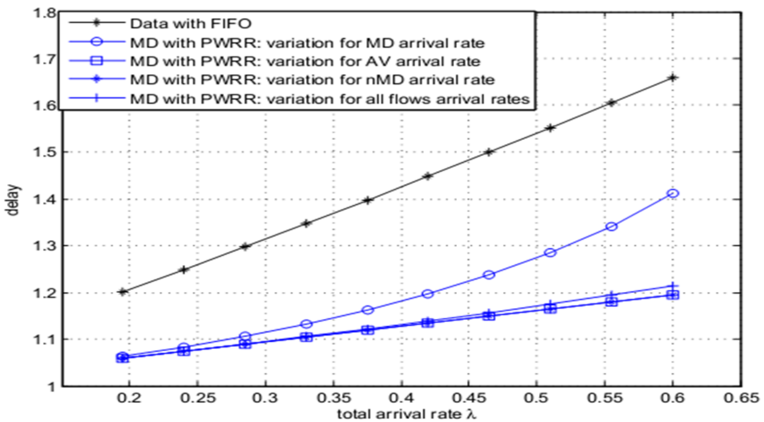
❑ EM:

In all these cases of arrival rates variations, PWRR is still better over FIFO with λ <0.55

Analytics in Matlab:

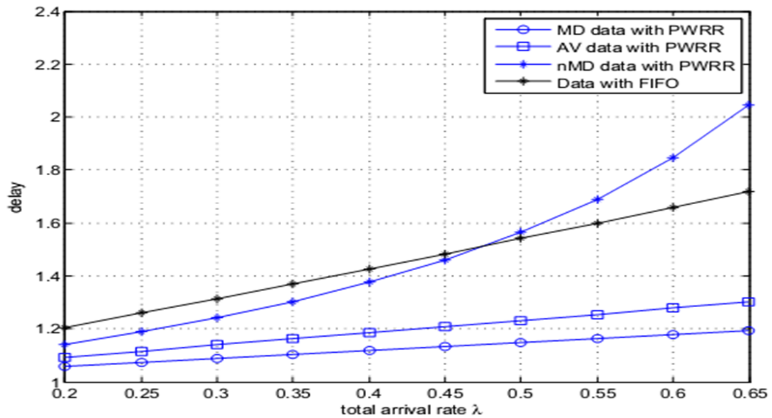
❑ MD, AV and nMD:

- MD and AV keep low delay for all λ variation
- nMD delay is also good for λ < 0.45



❑ MD:

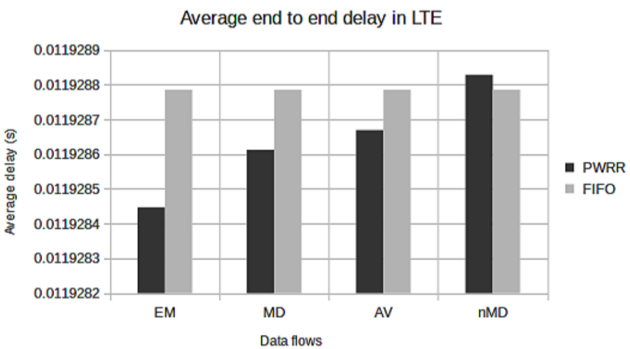
For all studied cases, WRR delay is much lower than FIFO

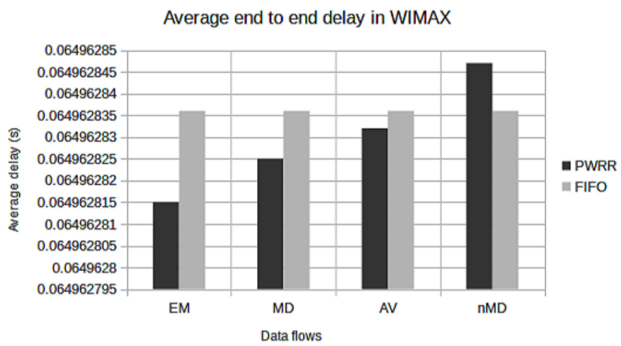


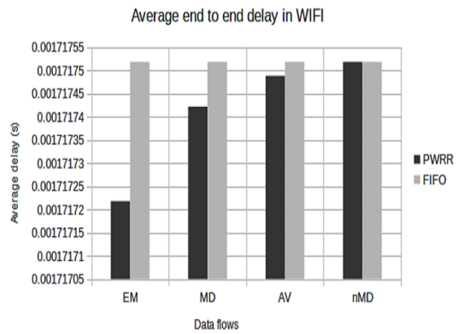
off-WBAN Scheduling

Scheduling model

Simulations with NS3: LTE – WIMAX - WIFI







- Peer networks have limited impact on our model
- Confirmation of analytical results

Summary of contributions

- **Energy efficient Intra and Inter-WBANs routing**
- **Intra-WBAN cooperation with MAC-in-MAC relaying**
- **WBAN traffic classes mapping and Off-WBAN scheduling**

Research outcome

Supervision activities

- **PhDs**
  - Audace Manirabona
  - Samia Belhadj
  - Nourchène Bradai
- **Interns**
  - Anis Harfouche
  - Miloud Otsmani
  - Salim Allal

Invited talks/tutorials

- Seminar TelCoN Lab, GIKI, Virtual (2019)

Related publications

Book chapters	Journals	International conferences
1	05	12

Perspectives

- **Extend off-WBAN proposal to E2E mapping solution in the context of 5G/6G**

- **Extend the intra-WBAN MAC relaying to inter-WBAN communications**

- **Explore the eHealth issues in the context of smart cities**
  - Heterogeneous access points to transmit data
  - Trusted vehicles for WBAN data collection
  - Outdoor security issues

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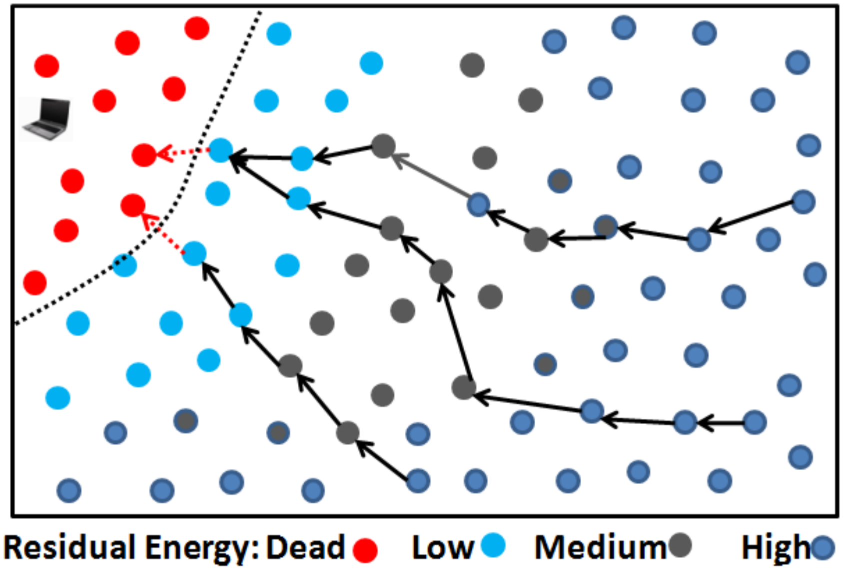
Data dissemination in large scale WSNs

Sink behavior

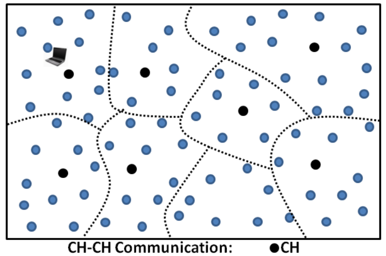
- Static sink
  - Low control traffic overhead
  - Energy hot spot problem
  - Network disconnection
- Mobile Sink
  - Better energy distribution
  - Sink location update
  - Increased control overhead



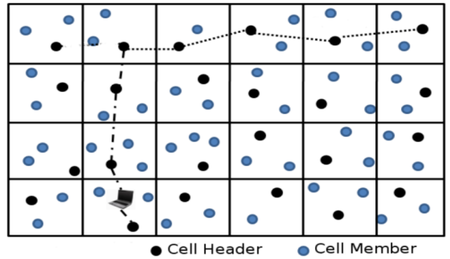
→ **We choose mobile sink option**

Network update techniques

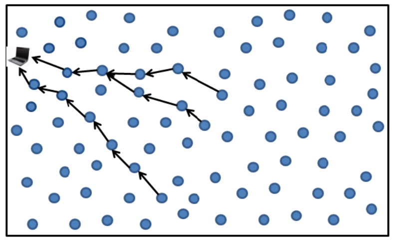
- Pure Flooding,
  - Directed Diffusion [1]
- Backbone structures
  - Clusters: LEACH [2], HCDD [3]
  - Virtual grids: TTDD [4]
- Tree-based protocols
  - Source-rooted trees: SEAD [5]
  - One tree per source



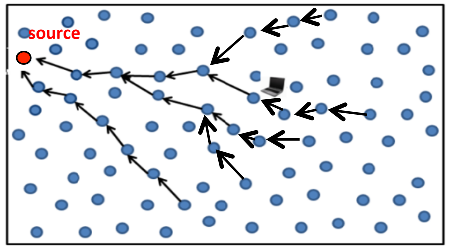
Clustering Technique



Virtual Grids



Sink rooted tree



Source rooted tree

- **Our proposal: Sink-rooted tree**
  - Single tree structure
  - Location update overhead

1. C. Govindan, R. Estrin, D. Heidemann, J. Silva: "Directed diffusion for wireless sensor networking", IEEE/ACM transactions on networking, 2003
2. A. Chandrakasan W. Heinzelman and H. Balakrishnan: "Energy-efficient communication protocol for wireless microsensor networks", HICSS 2000
3. Ching-Ju Lin, Po-Lin Chou, Cheng-Fu Chou: "HCDD: hierarchical cluster-based data dissemination in wireless sensor networks with mobile sink", IWCMC 2006
4. F. Ye, H. Luo et al. : "TTDD: two-tier data dissemination in large-scale wireless sensor networks", Wireless Networks, 2005
5. H. S. Kim, T. F. Abdelzaher, W. H. Kwon: "Minimum-energy asynchronous dissemination to mobile sinks in wireless sensor networks", SenSys 2003

SN-MPR routing algorithm for mobile sink WSNs

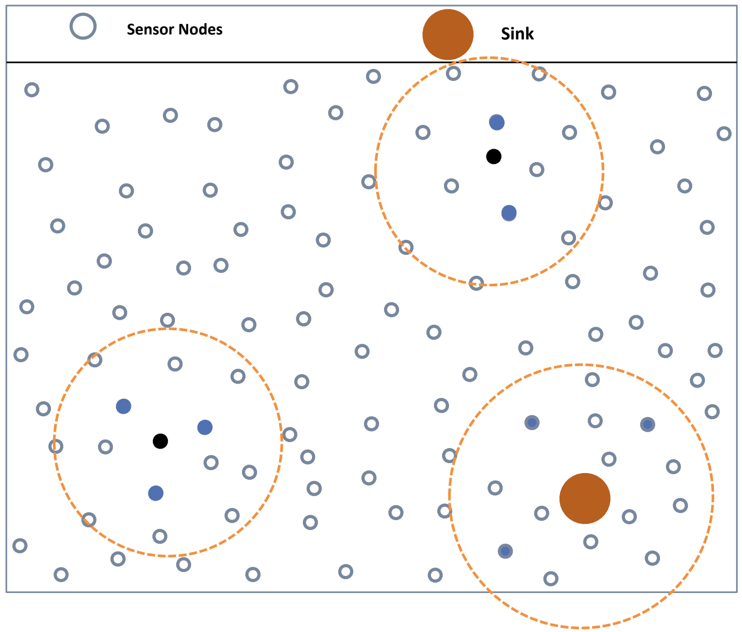
SN-MPR Principles

- Based on 2 control messages
  - **Hello** message for neighbor discovery
  - Sink Location Update (**SLU**) message for sink-rooted tree maintaining
- Sink uses **MPR** for SLU message broadcast [1,2]

1. Y. Faheem, S. Boudjit: "SN-MPR: A Multi-Point Relay Based Routing Protocol for Wireless Sensor Networks", IEEE CPScom 2010
2. Y. Faheem., S. Boudjit, K. Chen : "Dynamic Sink Location Update Scope Control Mechanism for Mobile Sink Wireless Sensor Networks", WONS 2011

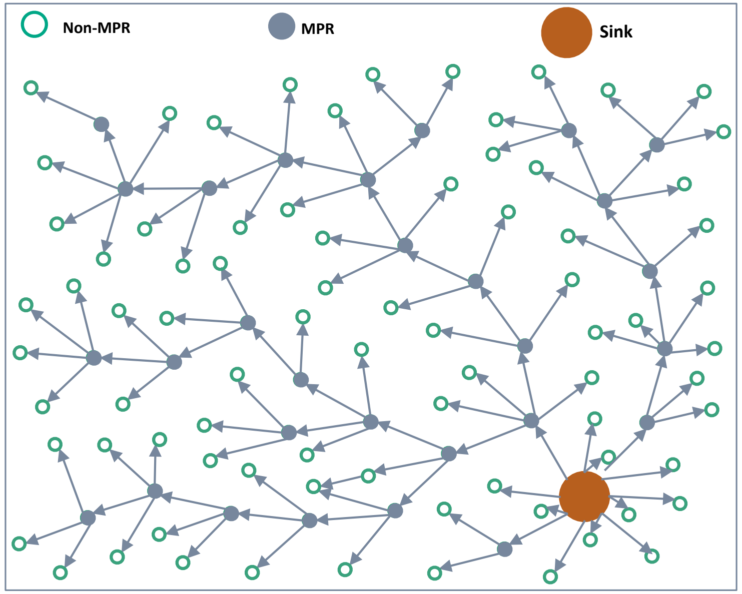
2-hop Neighbour Discovery

- Hello exchange among static sensors
  - Only at network initialization & battery depletion
- Hello exchange between mobile sink and sensors
  - Periodic (1 hello every 2 seconds)
  - Neighbors reply only in response to sink's hellos



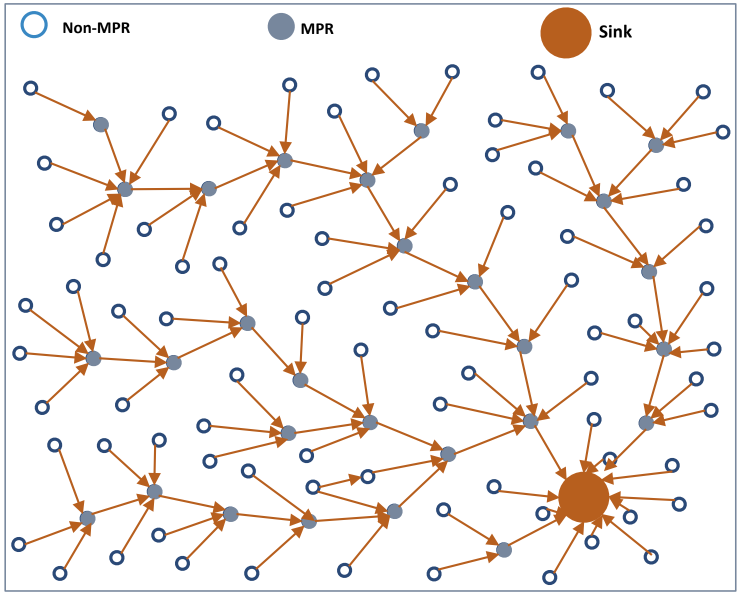
SLU message broadcast

- SLU broadcast (TC messages in OLSR protocol)
  - SLUs are sent every 5 seconds **only by sink**
  - Other MPRs do not transmit any broadcast (TC) messages



Reverse routing tree construction

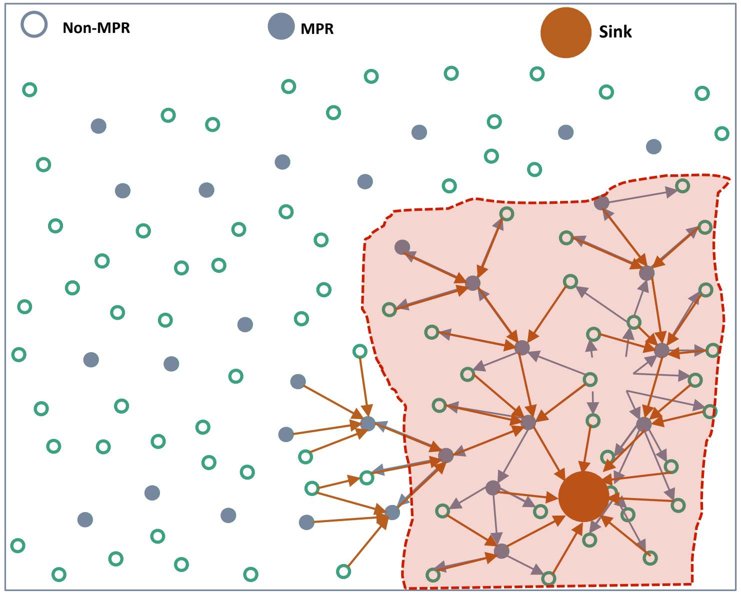
- Nodes use reverse path of SLU forwarding tree for sending data to the sink
  - Require only next hop information
  - Next_hop = neighbour from which SLU is received with minimum hop count



Reverse Tree Formation

Path Repair Mechanism

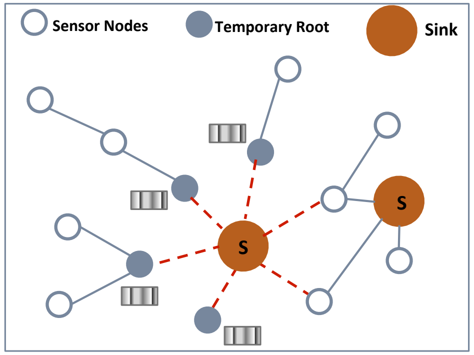
- Nodes keep track of reverse path of $SLU_{previous}$ message
- MPRs compare sender of SLU_{new} with $SLU_{previous}$ message
  - Rebroadcast if sender of $SLU_{new} \neq$ sender of $SLU_{previous}$
  - Else stop rebroadcast as the network behind this zone is not affected
- **SLU is retransmitted by MPRs only in a limited zone**



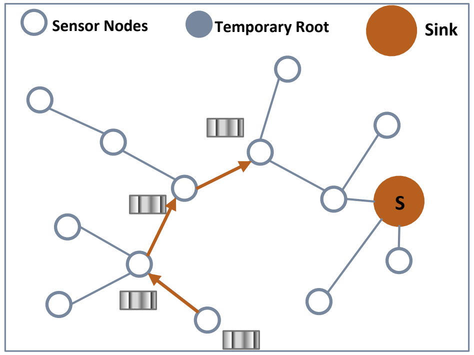
Mobile Sink

Preemptive buffering

- Unstable links between mobile sink & last relay neighbors
  - Results in data loss
- Preemptive buffering to increases data delivery ratio
- Packets buffered at maximum for few seconds



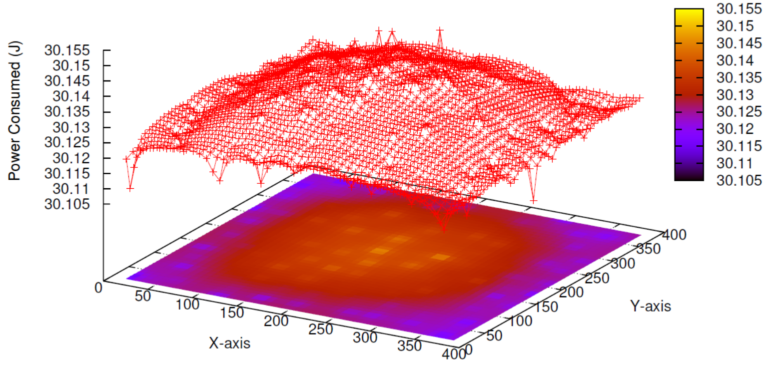
Buffering Activated at Temp. roots



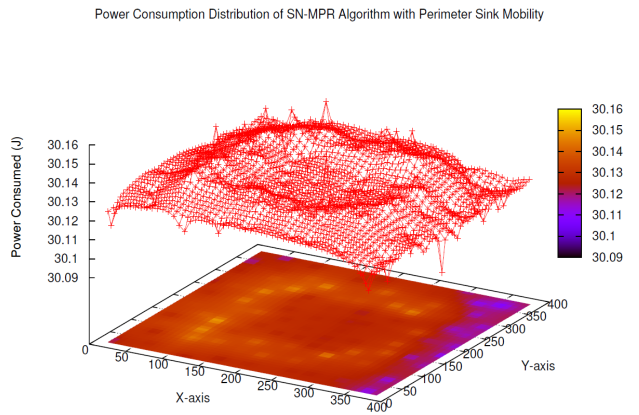
Back to Normal after SLU/Hello reception

Energy Distribution Efficiency of SN-MPR

Total Power Consumption :



Random sink mobility



Perimeter sink mobility

Summary of contributions

- **SN-MPR, a distributive MPR broadcast algorithm for mobile sink WSNs**
  - Minimizes sink location update costs
  - Feasible for real time applications

- **Duty-cycle SNMPR**
  - Prolong network lifetime
  - Suitable for Delay Tolerant Networks (DTNs)

Research outcome

Supervision activities

- **PhDs**
  - Yasir Faheem
  - Ismaïl Bezzine
- **Interns**
  - Nguyen Viet Haï

Invited talks/tutorials

- Seminar LRS Lab, Annaba, Algeria (2018)
- Seminar TelCoN Lab, GIKI, Virtual (2018)
- Tutorial COSI'14, Int. Conf, Bejaia, Algeria (2014)
- Seminar LETI Lab, Sfax, Tunisia (2014)
- Talk MathSTIC, USPN (2013)

Related publications

Book chapters	Journals	International conferences
0	02	08

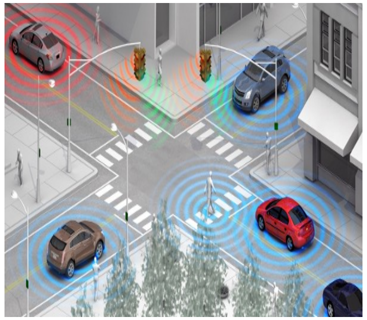
Perspectives

- **Performances of SN-MPR with high mobility speed of the sink**
  - Drones
  - Links breakages
- **SN-MPR with multiple sinks for data collection**
  - Synchronisation among sinks
  - Data collection redundancy

Outline

- Career Summary
- Context of my research
- Wireless Body Area Networks
- Large Scale Wireless Sensor Networks
- **Vehicular ad hoc Networks**
- Conclusion

Vehicular Ad hoc NETworks VANETs



- Vehicular Ad Hoc Networks (VANETs) aim to :
  - Enhance traffic Safety
  - Infotainment
- VANETs are a very specific case of MANETs characterized by :
  - High mobility
  - Frequent topology changes
  - Long lifetime of nodes (except for Drones)

→ **Bandwidth-aware routing proposal**

Geocast routing in VANETs

- Geocast = Geographic Broadcast

- Geocast routing technique principle
  - One source node
  - Routing data to one destination area
  - All vehicles located in the destination area

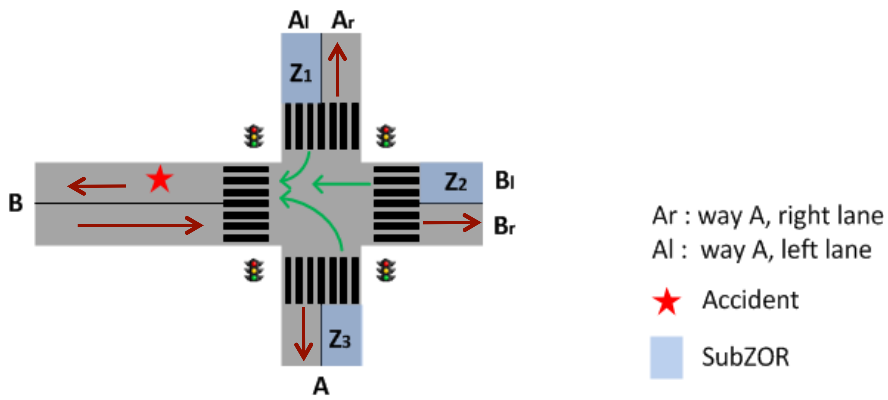
- → **Geo-SUZ: bandwidth-aware routing proposal**

Geocast routing in VANETs

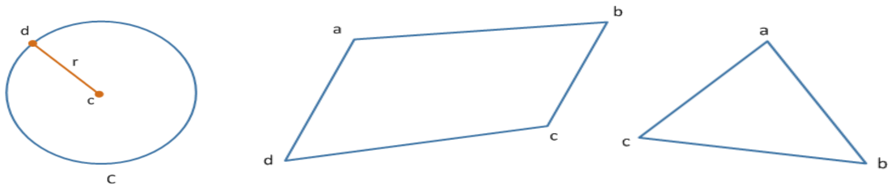
- Geocast = Geographic Broadcast
- Geocast routing technique principle
  - One source node
  - Routing data to one destination area
  - All vehicles located in the destination area
- **Destination area = Zone Of Relevance (ZOR)**

Zone of Relevance (ZOR)

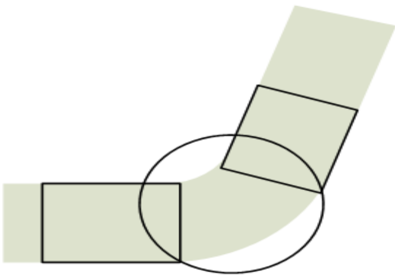
- The destination area ZOR is a set of sub-ZORs
  - ZOR = ZOR_1 u … u ZOR_n
  - It can be of any form
  - Confined in a unique area or be in several places

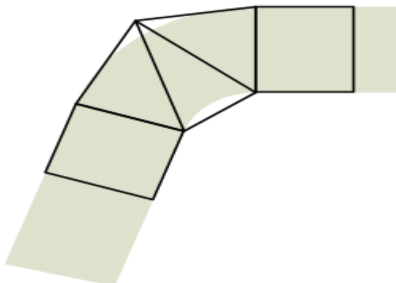


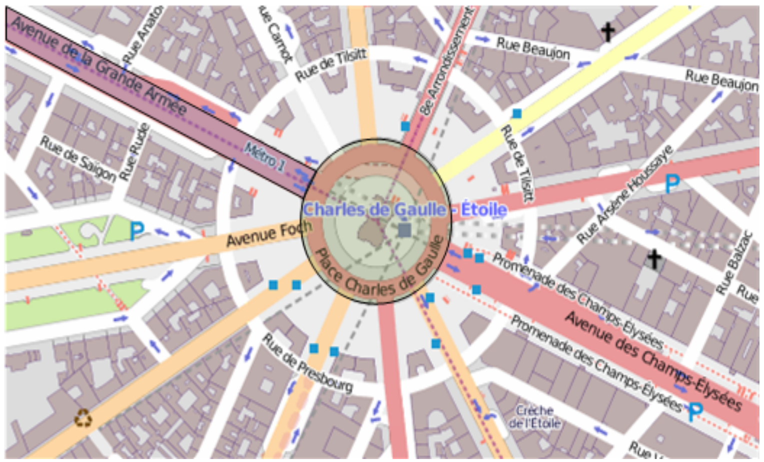
Zone of Relevance (ZOR)



- We use simple geometrical shapes for **sub-ZORs**
  - Circle, triangle et quadrilateral
- Motivation
  - Easy to represent mathematically (2, 3 or 4 coordinates)
  - Possible to adapt to the real shapes of roads



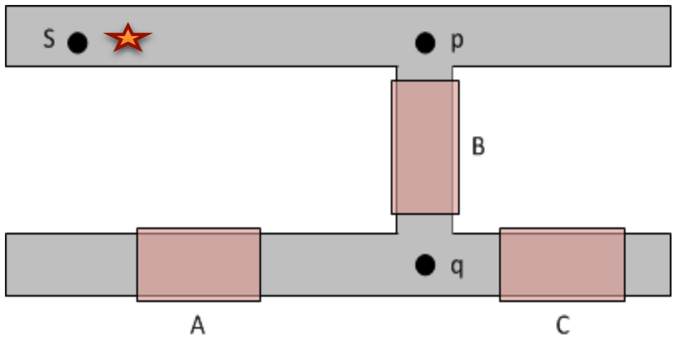




Routing problem

- Source S reports an event to sub-ZORs A, B and C
  - 3 flows of the same message through the vehicle P
  - Followed by 2 flows of the same message through vehicle q

  → **Send one message to sub-ZORs situated in the same direction !**



Diffusion Scenario (DS)

Question : How to know if two sub-ZORs are in the same direction ?

GeoSUZ Algorithm

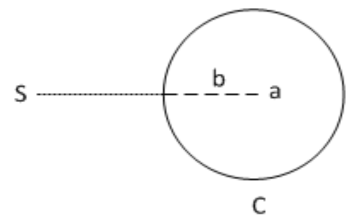
Geometrical vision angle technique

1. **Distances between the source and the list of sub-ZORs**

- **Circular** sub-ZOR (C : {a, b}) :

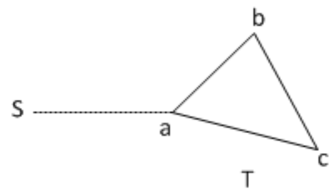
$$d_{ab} = \sqrt{(x_b - x_a)^2 + (y_b - y_a)^2}$$

$$d_{SC} = d_{Sa} - b$$



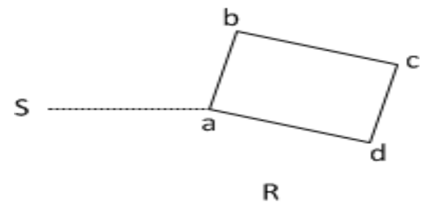
- **Triangular** sub-ZOR (T : {a, b, c}) :

$$d_{ST} = \min\left(d_{Sa}, d_{Sb}, d_{Sc}\right)$$



- **Quadrilateral** sub-ZOR (R : {a, b, c, d}) :

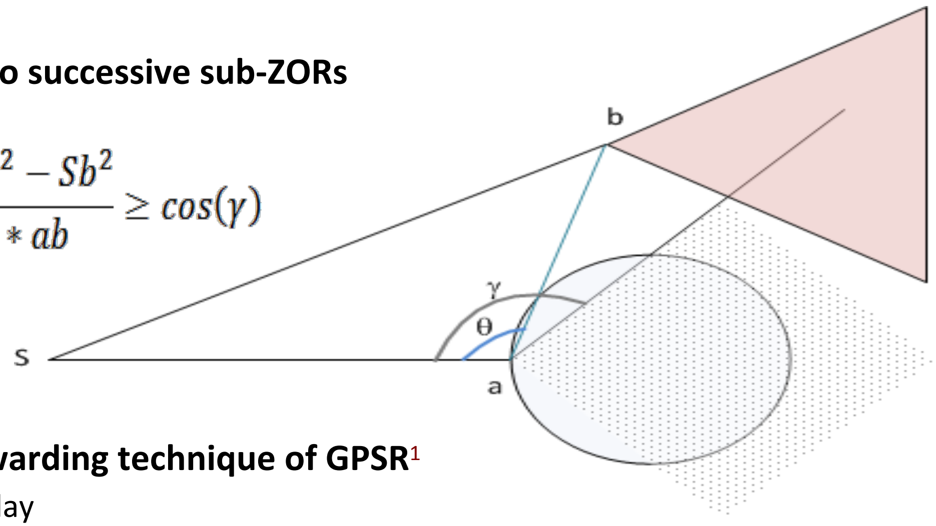
$$d_{ST} = \min\left(d_{Sa}, d_{Sb}, d_{Sc}, d_{Sd}\right)$$



GeoSUZ Algorithm

Geometrical vision angle technique

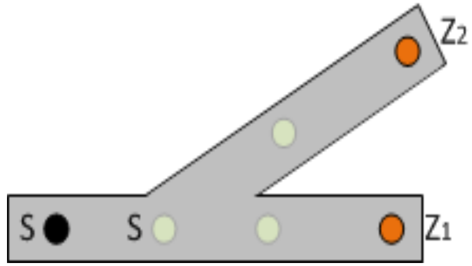
2. **Sort the list of sub-ZORs by increasing distances**
3. **Calculate the angle θ between the source and each two successive sub-ZORs**
   - Fixe the angle γ arbitrarily (135° in general)
   - Same direction if the condition (θ = Sâb) < γ : $\frac{Sa^2 + ab^2 - Sb^2}{2 * Sa * ab} \geq cos(\gamma)$
   - A quality factor $\lambda \in]0,1[$ allows to adapt the γ angle for a better routing quality



4. **Fragment the message M accordingly**
5. **Relaying between sub-ZORs is done with Greedy Forwarding technique of GPSR[1]**
   - The closest neighbor from the destination becomes the relay

1. Brad Karp, H. T. Kung: "GPSR: greedy perimeter stateless routing for wireless networks", Mobicom 2000.

GeoSUZ Algorithm



- Message structure
  - **m** : the message
  - **S** : source ID
  - **Z** : sub-ZORs array

$$M[m, S, Z], \qquad Z = \{Z_1, Z_2\}$$

- Pre-fragmented massage

$$M[m, S, \{Z_1, Z_2\}] \rightarrow M_1[m, S, \{Z_1\}].M_2[m, S, \{Z_2\}]$$

  - **M1** : destined to all sub-ZORs located in the same direction.
  - **M2** : destined to the rest of sub-ZORs (located anywhere and not all in the same direction).

- Fragmented message

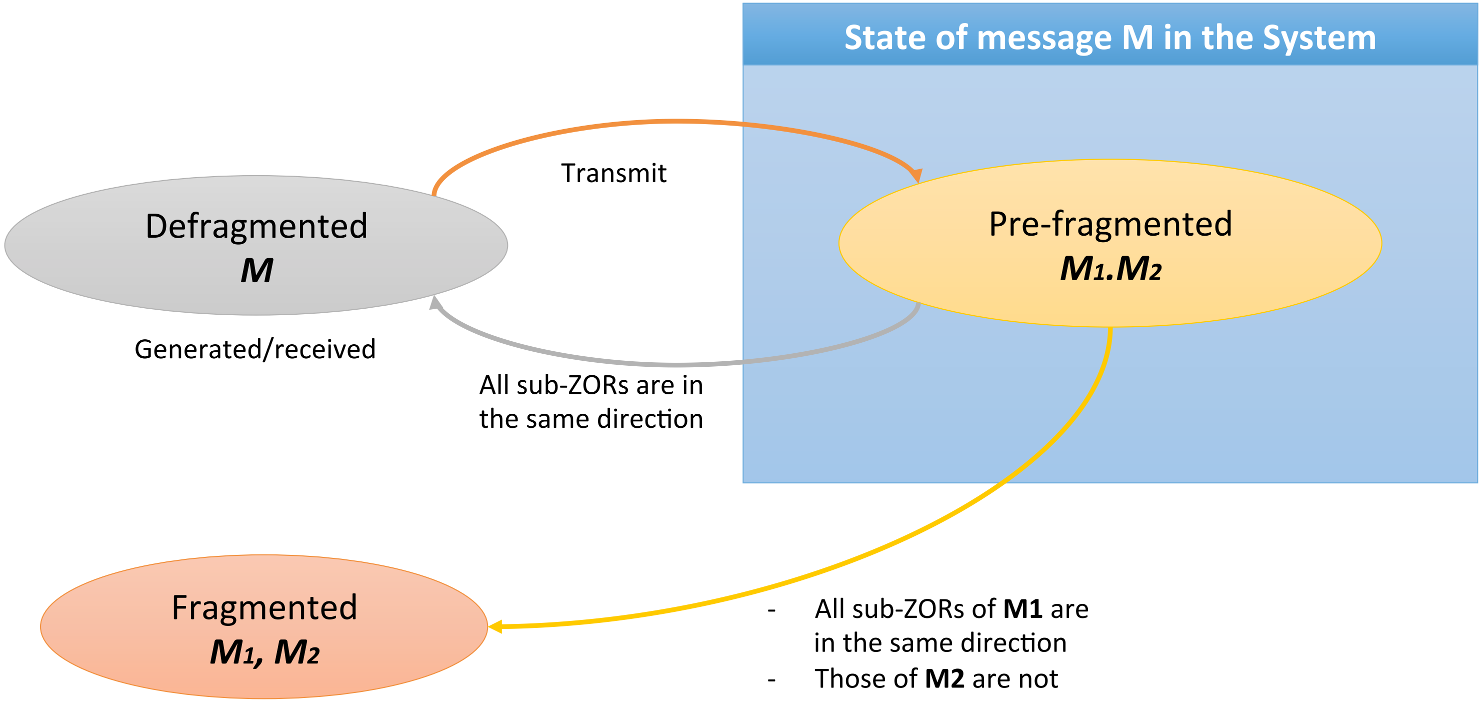
$$M_1[m, S, \{Z_1\}].M_2[m, S, \{Z_2\}] \rightarrow M_1[m, S, \{Z_1\}], M_2[m, S, \{Z_2\}]$$

- Defragmented message

$$M_1[m, S, \{Z_1\}].M_2[m, S, \{Z_2\}] \rightarrow M[m, S, \{Z_1, Z_2\}]$$

1. S. Allal, S. Boudjit: " Geocast Routing Protocols for VANETs: Survey and Geometry-Driven Scheme Proposal", JISIS, ISYOU/ISEP-IPP, 2013.
2. S. Allal, S. Boudjit: "GeoSUZ: A Geocast Routing Protocol in Sub-ZORs for VANETs", IEEE ICAIT 2012.

GeoSUZ Algorithm

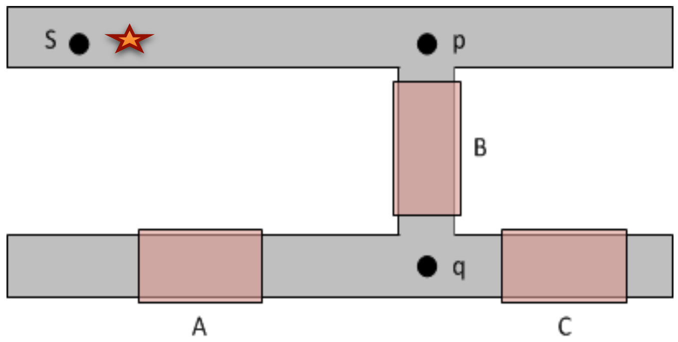


Numerical results
GeoSUZ vs GPSR

Some numerical results on the previous scenario (DS)

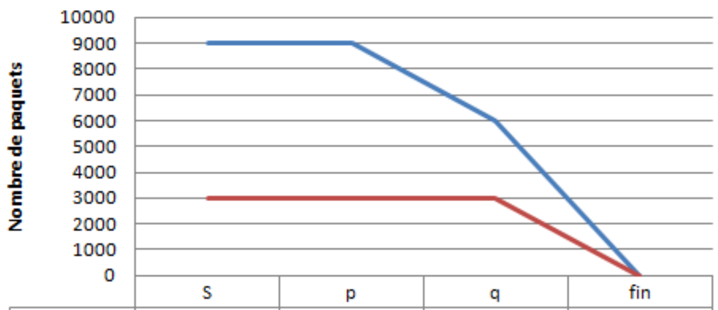
- The source **S** generates 3000 messages
- A, B and C are in the same direction

→GeoSUZ: 1 copy of the message for all
→GPSR: 1 copy for each zone



Diffusion Scenario (DS)

Résultats numériques

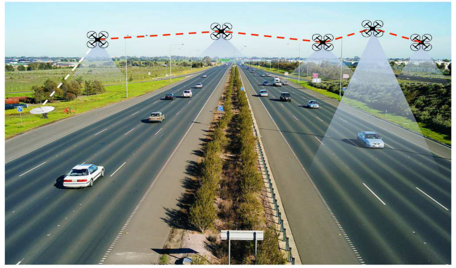


	S	p	q	fin
GPSR	9000	9000	6000	0
GeoSUZ	3000	3000	3000	0

Unmanned Aerial Vehicles

UAVs

- Drones used to be reserved for military applications
- They become more popular in many collaborative civilian applications
- Widely deployed in France[1,2]
  - Forest fire surveillance
  - Highways video surveillance
  - Many other applications …
- However, radio coverage is the main issue for real-time applications
  - How to join ground base stations when drones are far away ?
- Mutli-hop transmission might be a solution
  - **Problem of multi-hop routing in a highly dynamic topology !!**



1. http://www.statistiques.developpement-durable.gouv.fr/lessentiel/ar/368/1239/feuxforet.html
2. http://www.interieur.gouv.fr/Actualites/Dossiers/Les-drones-au-servicede-la-securite/Identifier-en-temps-reel-les-contours-d-un-sinistre

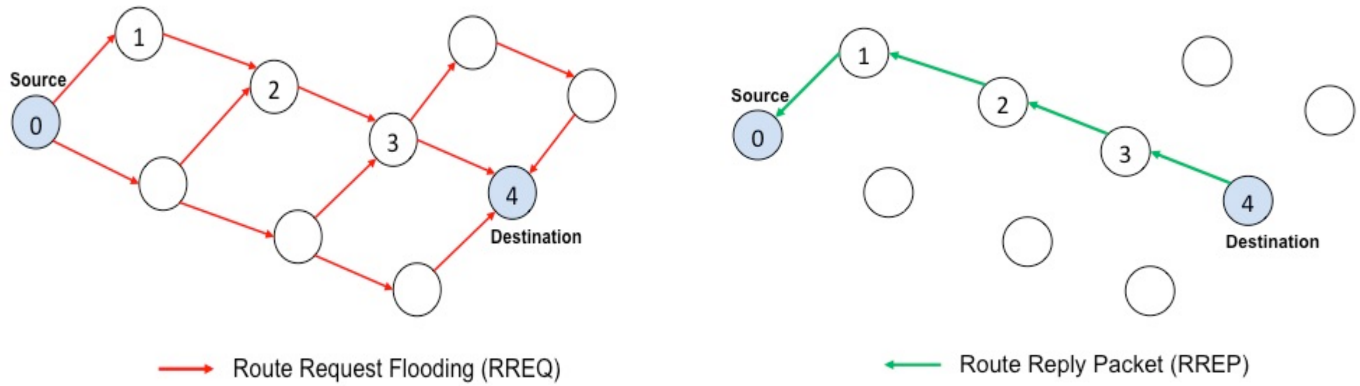
Multi-hop Routing in UAVs

- Possible routing solutions
  - Reactive routing
    - Limited overhead
    - But more delay to compute routes !
  - Proactive routing
    - Important overhead
    - But route available immediately !
- Our solutions : BR-AODV, multi-hop routing solutions for UAVs
  - **Based on AODV (Ad hoc On Demand Distance Vector) for route computation [1]**
  - **Swarm intelligence for active path connectivity maintenance (Boids of Reynolds) [2]**

1. C. Perkins, E. Belding-Royer, and S. Das. Ad hoc on-demand distance vector (aodv) routing. In IETF, RFC 3561, 2003
2. Craig W. Reynolds. Flocks, herds, and schools: a distributed behavioral model. Computer Graphics, 1986

BR-AODV routing proposal

A. AODV routing protocol for on-demand route computation



- Destination in BR-AODV ➡ a drone with an established connection with a ground base station

1. N. Bahloul, S. Boudjit, M. Abdennebi, D. E. Boubiche: "A Flocking-based on Demand Routing Protocol for Unmanned Aerial Vehicles", JCST, Springer, 2018.
2. N. Bahloul, S. Boudjit, M. Abdennebi, D. E. Boubiche: "Bio-inspired on Demand Routing Protocol for Unmanned Aerial Vehicles", IEEE I3CN, 2017.

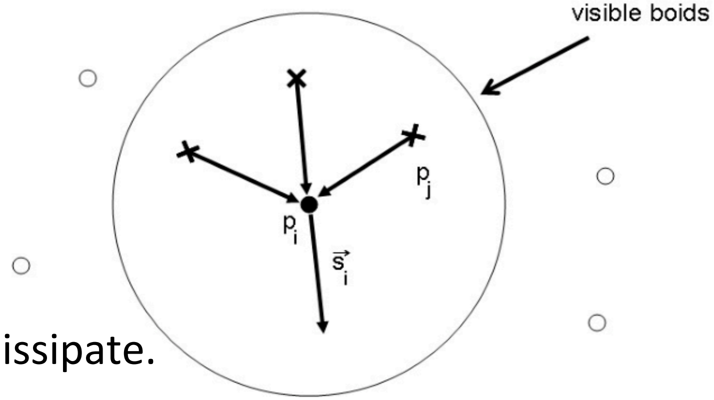
BR-AODV routing proposal

B. Boids of Reynolds for active path maintenance

1. Separation rule

- Separation steer denoted V_{si} is the negative sum of vectors defined by the position of the boid $\boldsymbol{b}_i$ and each visible boid $\boldsymbol{b}_j$

$$v_{s_i} = - \sum_{b_j \in \delta_i : d(b_j, b_i) < z} (p_i - p_j)$$



- If only this steering force is applied, the flock will dissipate.

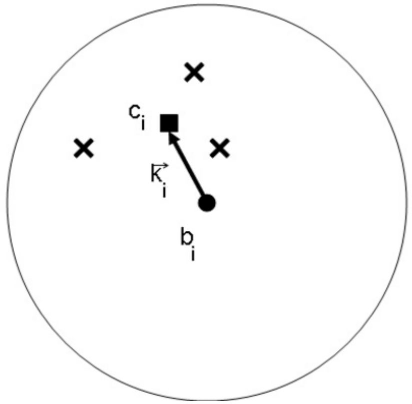
BR-AODV routing proposal

B. Boids of Reynolds for active path maintenance

2. Cohesion rule

- Steering force which moves the boid towrad the center of the visible flock
- It acts as the complement to the separation
- Cohesion velocity of the boid $\boldsymbol{b_i}$ is denoted by $\boldsymbol{Vc_i}$
- $\boldsymbol{C_i}$ is the center of the visible boids of the boid $\boldsymbol{b_i}$

$$v_{c_i} = c_i - p_i \ \ Where \ \ c_i = \frac{1}{|\delta_i|} \sum_{b_j \in \delta_i} p_j$$



- If only this steer is applied, the flockmates will merge into one single position

BR-AODV routing proposal

B. Boids of Reynolds for active path maintenance

3. Alignment rule

- Boids tend to align with the velocity of their flockmates
- This steer denoted by V_{ai} is calculated as the average velocity of the visible flockmates

$$v_{a_i} = \frac{1}{|\delta_i|} \sum_{b_j \in \delta_i} v_j$$

- If a boid accelerates too much it can jump out of the visibility sphere of the flockmates and eventually escape

BR-AODV routing proposal

B. Boids of Reynolds for active path maintenance

Combining the steers

- The new displacement of each UAV is calculated as follows:

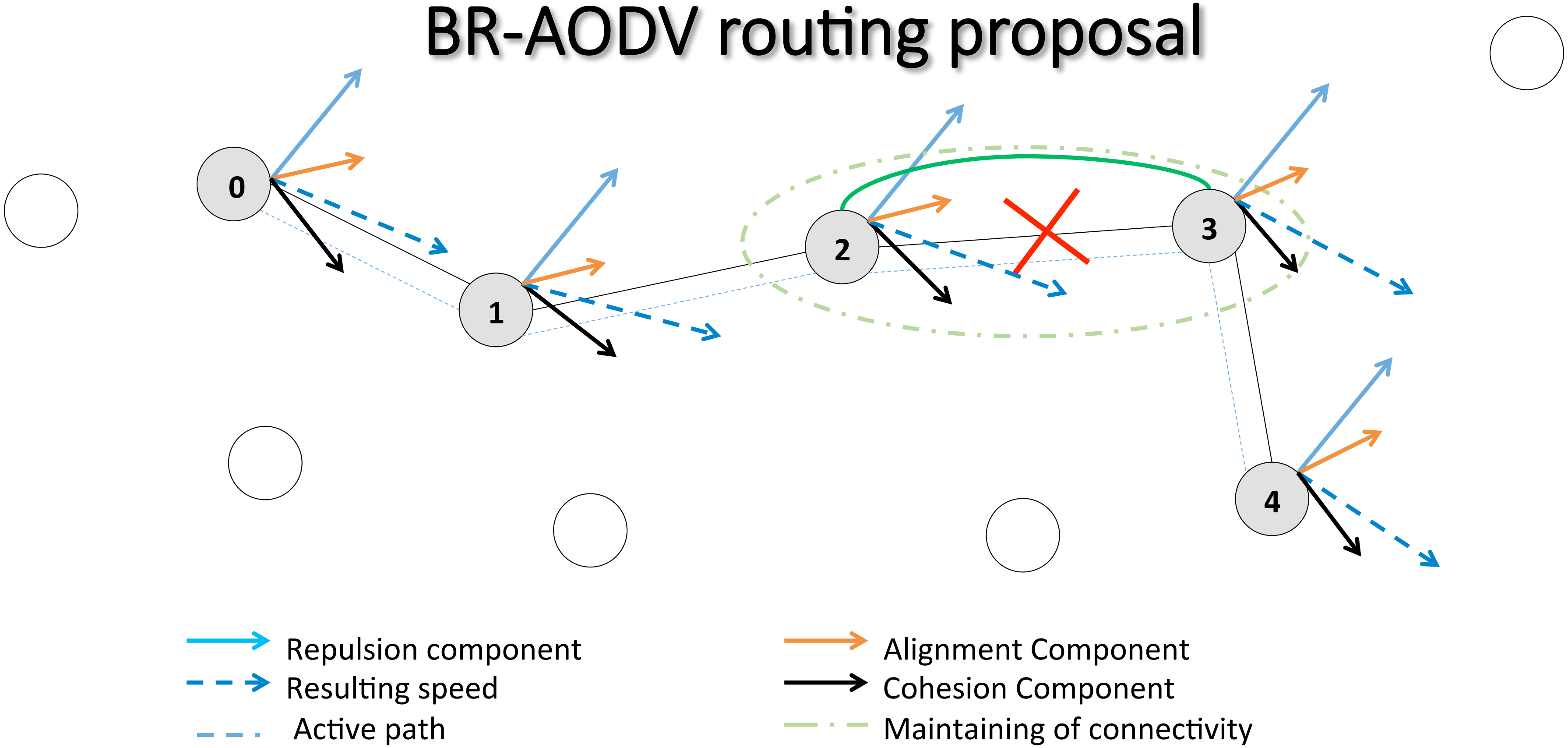
$$p_i(t+1) = p_i(t) + v_i(t+1)$$

Where

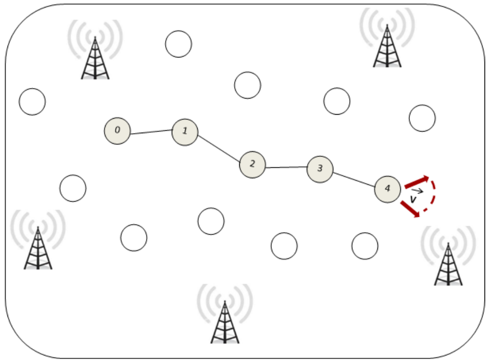
$$v_i(t+1) = \alpha.\left(w_s.v_{s_i}(t) + w_a.v_{a_i}(t) + w_c.v_{c_i}(t)\right) + \left((1-\alpha).v_i(t-1)\right)$$

- **α** is the smoothing or memory parameter in [0,1] interval. It indicates the influence rate of previously gathered information on the computation of the UAV current velocity.
- Parameters $\boldsymbol{w_s}$, $\boldsymbol{w_a}$, $\boldsymbol{w_c}$ are weights taken in [0,1] interval. They indicate the importance of each steer in the accuracy of the new velocity.

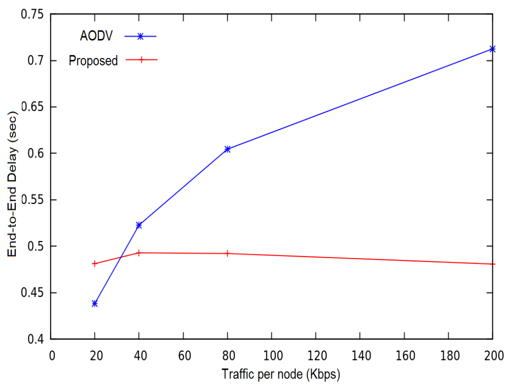
BR-AODV routing proposal



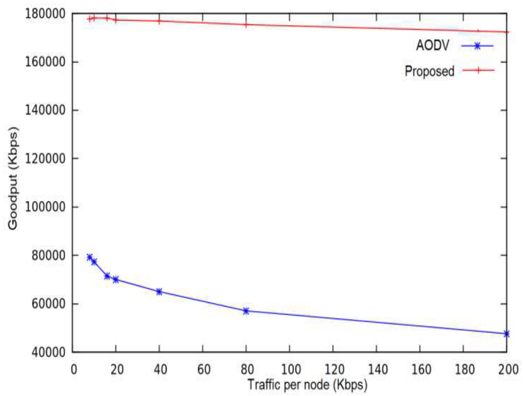
Simulation results



- Fleet of 5 nodes and
- 10 nodes to generate background traffic load



- End-to-end delay significantly improved for high traffic load
- Due to active paths maintenance and re-routing avoidance



- The Goodput of BR-AODV is almost stable even when traffic load increases

Summary of contributions

- **Geo-SUZ: a Geocast routing protocol for VANETs**
  - **Vision angle technique to limit the overhead**
  - **Save bandwidth**

- **BR-AODV: Swarm intelligence based reactive routing protocol for UAVs**
  - **Route robustness**

Research outcome

Supervision activities

- **PhDs**
  - Salim Allal
  - Nour El Houda Bahloul
  - Shahab Haider
  - Leila Benarous
  - Nouman Bashir (ongoing)
  - Fatima Zahra Rabahi (ongoing)
- **Interns**
  - Nazim Abdeddaim

Invited talks/tutorials

- WRE, IEEE Conf., Islamabad (2018)

Related publications

Book chapters	Journals	International conferences
1	06	08

Perspectives

- **Extend GeoSUZ to an optimal E2E delivery**
  - Geo-SUZ between ZORs
  - Optimal broadcast inside a ZOR
  - MAC issues

- **Integrate UAVs with connected and autonomous vehicles on the ground**
  - Provide alternative routes to broken air connection among UAVs
  - Ensure quality and stability of routes despite the mobility of UAVs

- **Machine learning for routing decision-making in UAV networks**
  - Autonomy to dynamically adapt flight paths in response to some factors (weather, hardware failure, …)
  - Ability to predict the moves of other UAVs through similar factors
  - Estimate more stable routing paths in terms of ground base stations accessibility

Outline

- Career Summary
- Context of my research
- Wireless Body Area Networks
- Large Scale Wireless Sensor Networks
- Vehicular ad hoc Networks
- **Conclusion**

Conclusion

- Different application oriented contributions for routing and data dissemination (VANETs, UAVs, WBANs)
- Contributions to enhance the quality of service (QoS) in health monitoring systems (WBANs)
- But we are still far from reaching completely operational systems

My goal is to continue to contribute to the efforts of making theses systems a reality

Acknowledgment

I would like to thank :

- All my doctoral students and Interns without whom theses results would not have been achieved
- All my research collaborators in France and worldwide
- All my family and friends for their unconditional support