# Smarter Cities related R&D Projects

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# Intelligent Energy: MoreSolar project



Monitoring & prediction of solar production for Moroccan solar installations (MoreSolar)

- Objectives:
  - Develop a solar-powered WSN
  - Develop a hybrid (wired & wireless) monitoring solution
  - Develop methods to predict power production and faults using ML

- Funded by IRESEN
- Started May 2014
- Duration: 3 years

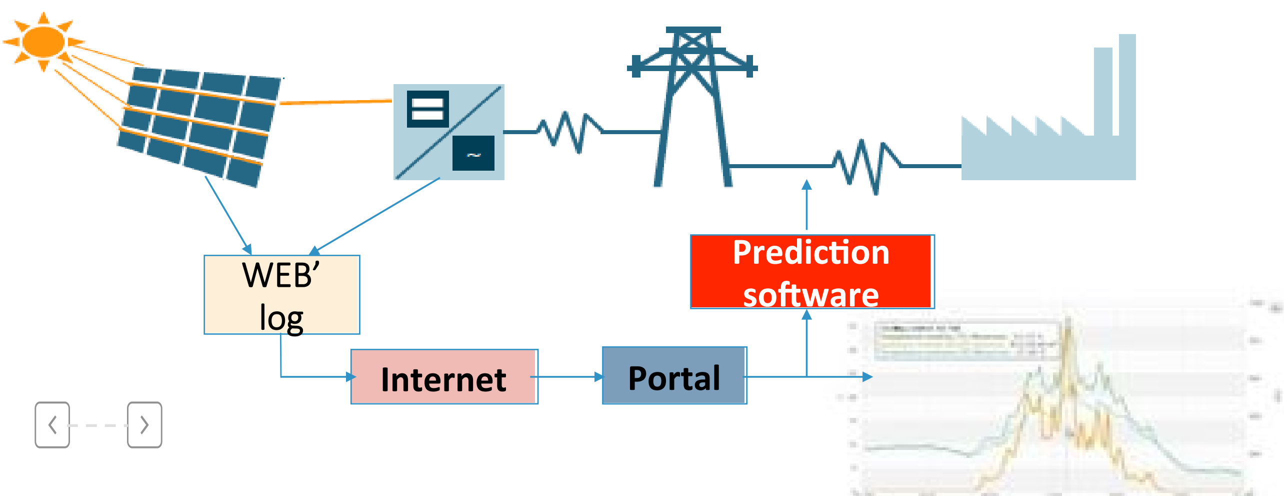
UIR Université Internationale de Rabat

TELECOM ParisTech

Université Ibn Tofail

UNIVERSITY OF LEEDS

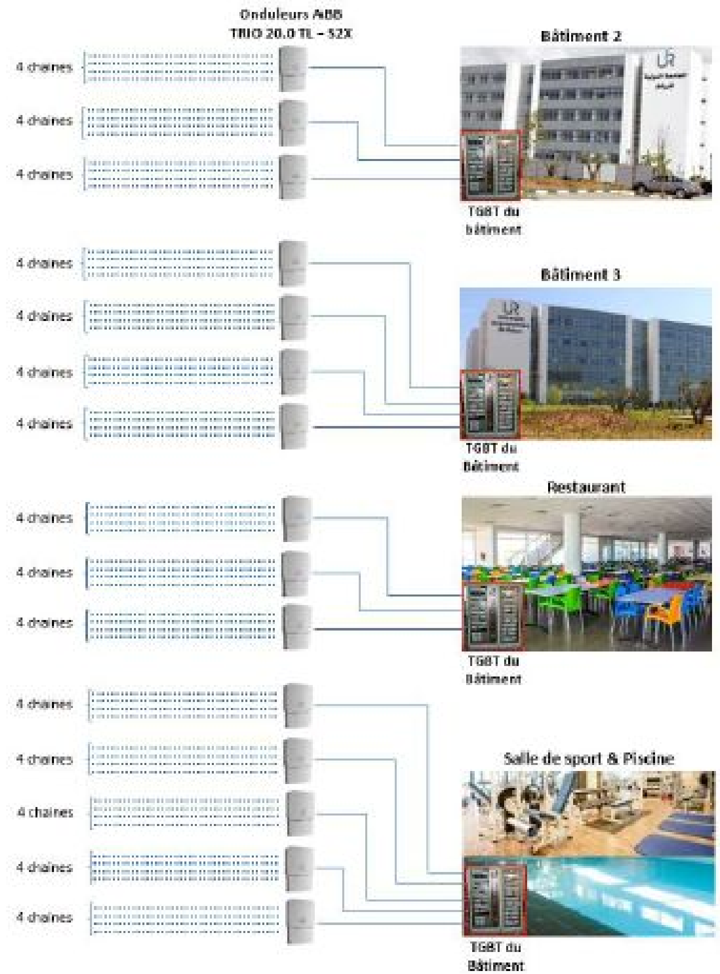
Jet alu Maroc



# MoreSolar project: pilot site 1

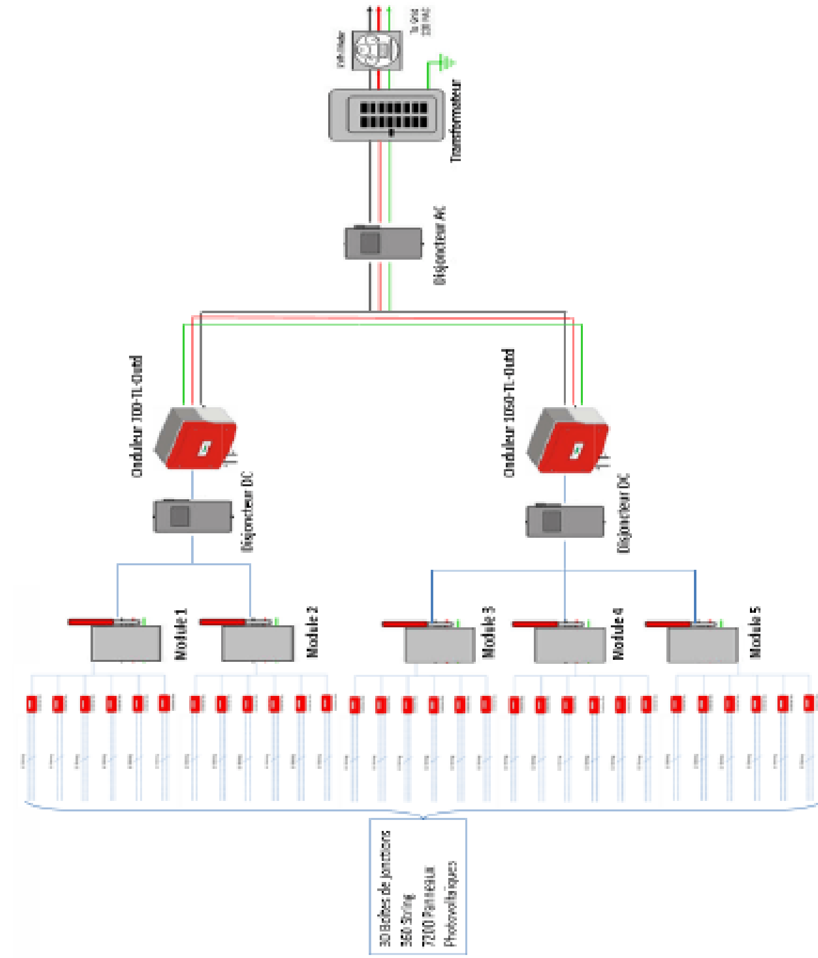


- UIR's solar system




- 327 kW (1320 PV panels; 2500 m$^2$)
- 20% reduction of electricity bill
- Minus 260 tons of CO2

# MoreSolar project: pilot site 2

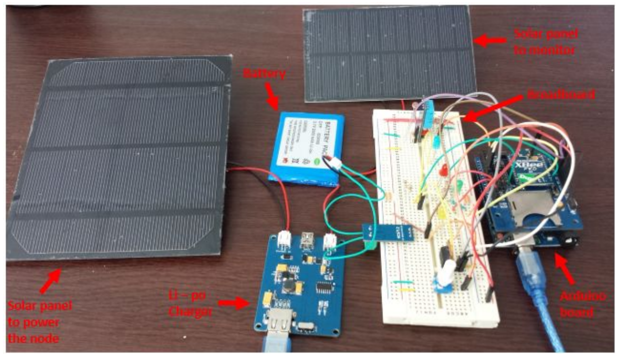


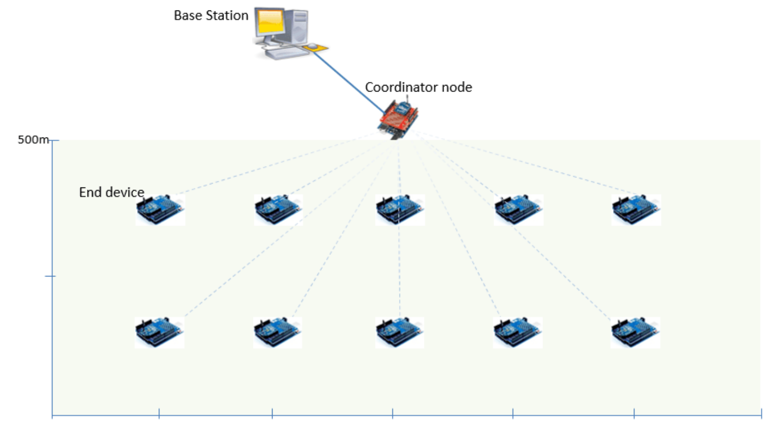

- 2 MW (7140 PV panels, 50000m$^2$)
- 30% of current electricity need of Kenitra's Atlantic Free Zone

# MoreSolar project: work progress

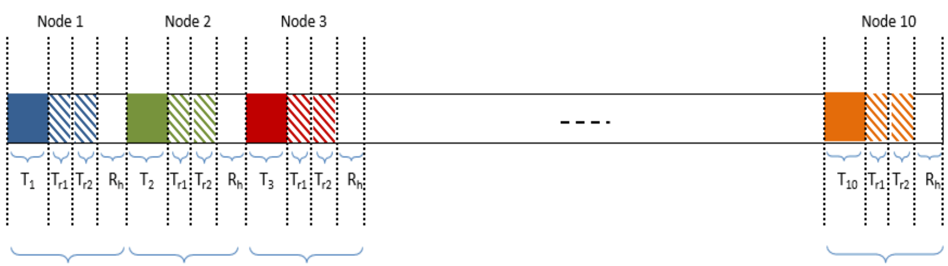
– Developed a solar-powered ZigBee WSN

Solar panel:
5.5V – 450mA, 3W;
7.4 Wh




– Energy-aware MAC and duty cycle




- Energy consumed daily (Wh):

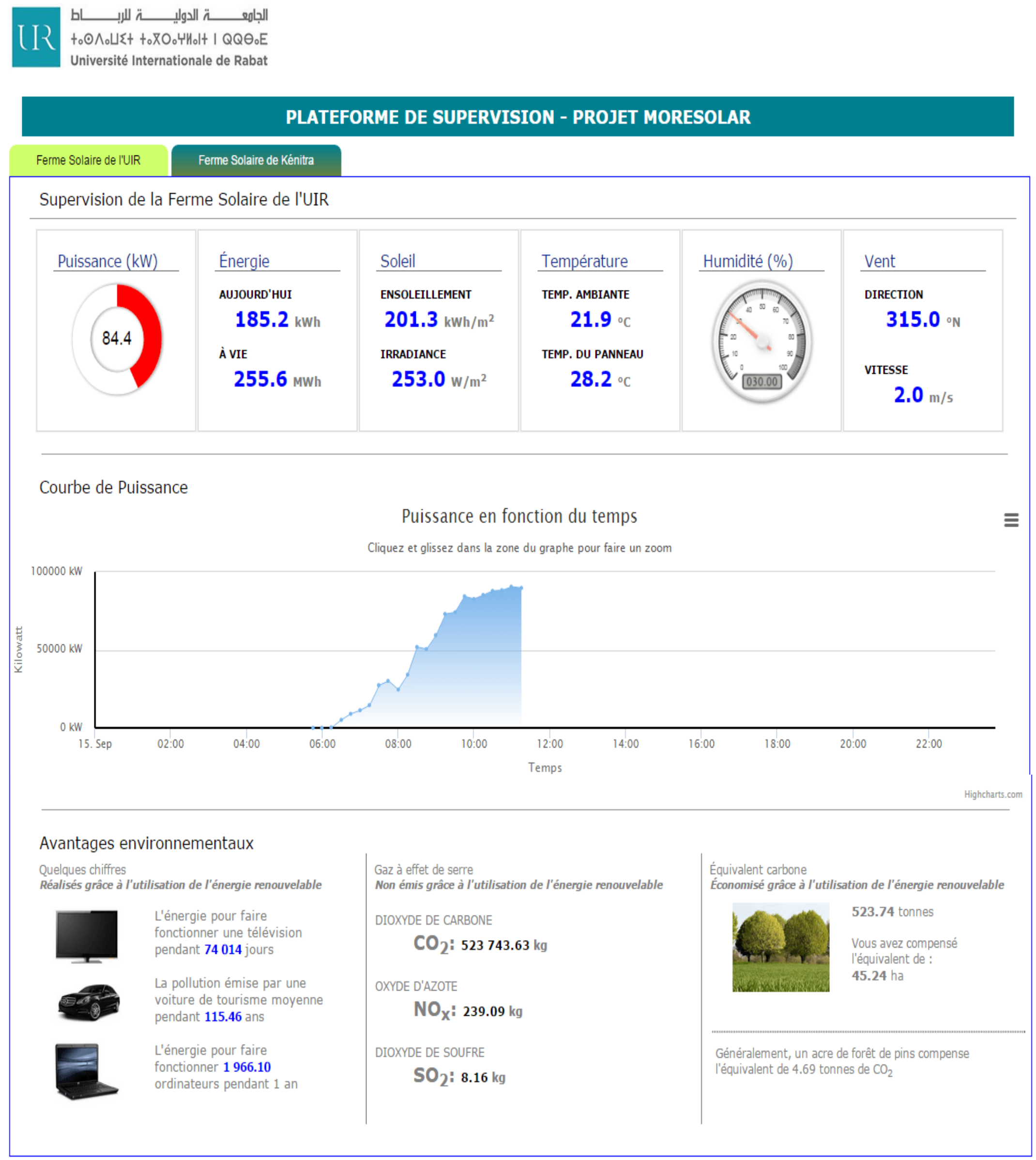
$$E(T) = 4.973 + \frac{0.3}{T}$$

T>0.081

# MoreSolar project: work progress

– Web interface:

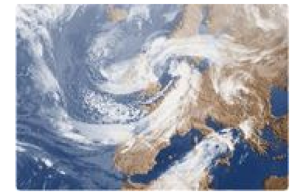
- Interface developed using **HTML**, **CSS** and **JavaScript**.
- **Ajax** used for data request, display and real-time update
- **JSON** used for data format for the webpage
- Web server on the coordinator's Arduino Mega card

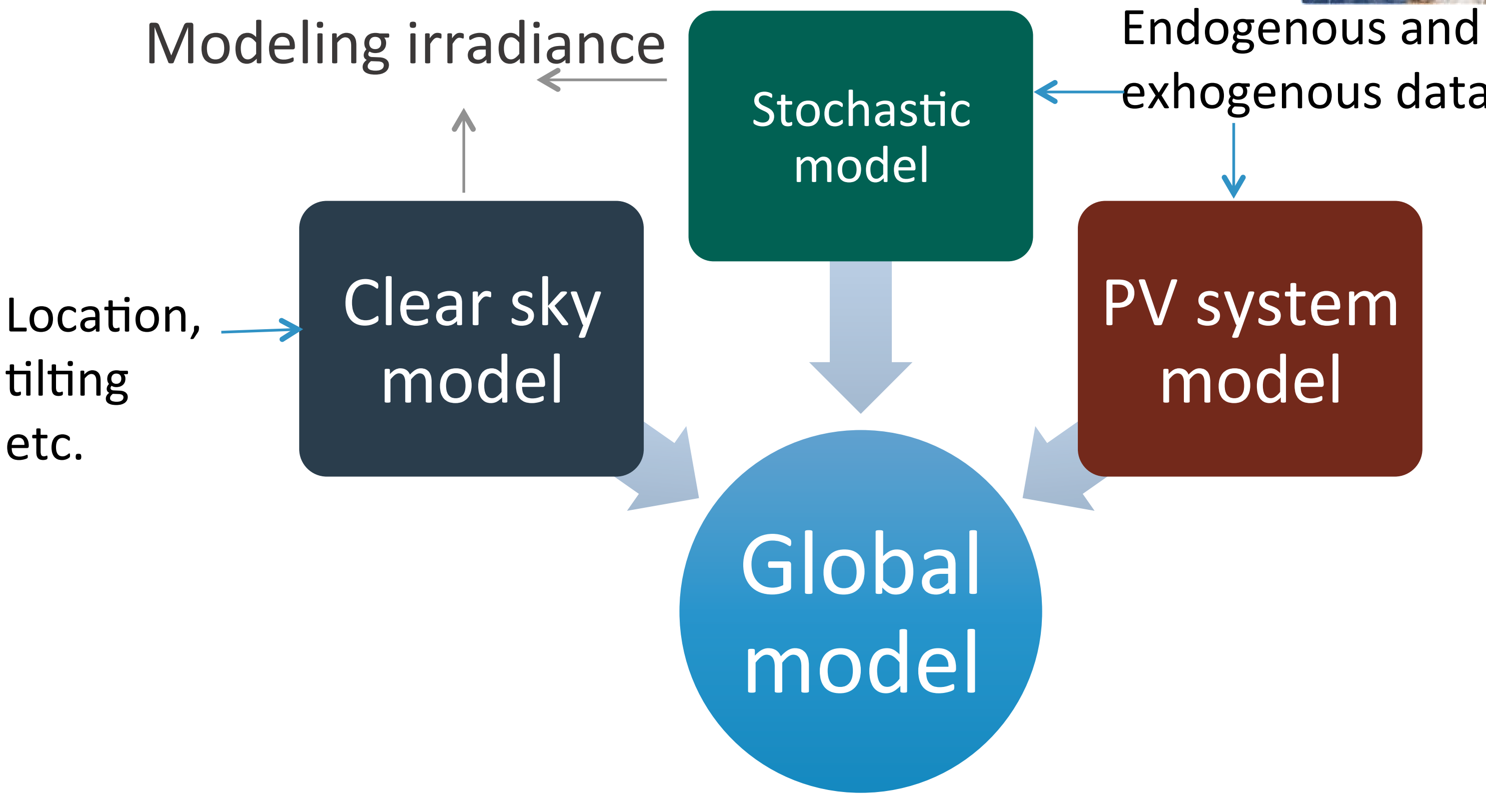


# MoreSolar project: work progress



– Solar power prediction





# MoreSolar project: work progress



Aim: Retrieve radiation components from sky image characteristics, with the goal of irradiance forecast

Approach: Use machine learning algorithms with image features and radiation measurements

Fisheye Network IP Dome Camera

Images every 10 seconds from sunrise to sunset

Global horizontal radiation (1s samples)

# Cyber-Security: PHY-SEC project

Physical layer security for wireless networks (PHY-SEC)

- Objective: use signal processing to improve security (traditionally a higher-network-layer issue) at the physical layer (beamforming, directional modulation, artificial noise, etc.)
- May be useful for smart grid wireless comms..

- Funded by US Army
- 2011-2014

الجامعة الدولية للرباط
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Université Internationale de Rabat

U.S. Army Research Laboratory

UNIVERSITY OF LEEDS

# ITS: PreTraffic project



Development of prediction techniques of road traffic in urban areas (PreForecast)

- Objective: use GPS data, geocoding, weather conditions (and video analytics) to predict road traffic in Moroccan cities

Partners: IBM, Urbasoft, Supratour…

IBM Faculty award (2013)

# ITS: TrafficMan project

Development of an integrated system for traffic management (TrafficMan)

- Funded by CNRST
- Starts Jan 2016
- Duration: 3 years

- Objectives:
  - Video-based traffic estimation
  - Video-based anomaly detection
  - Video-based traffic lights control
  - Video-based infraction detection

Partners: MASCiR, city council, other Moroccan universities

# ITS: HowDRIVE project



How do Moroccans DRIVE? a Quantitative Behavior Analysis (HowDRIVE)

- Submitted to CNRST

- Objectives:
  - Develop models for the drivers' behaviors in different conditions
  - Develop models relating the driver behavior to the crash risk.
  - To develop a road safety simulator and investigate cost-effective safety improvement measures.
- Partners: SUPRATOUR, MASCiR, University of Leeds, IBM, UPM6

# Traceability and Logistics: RFID-Sort project



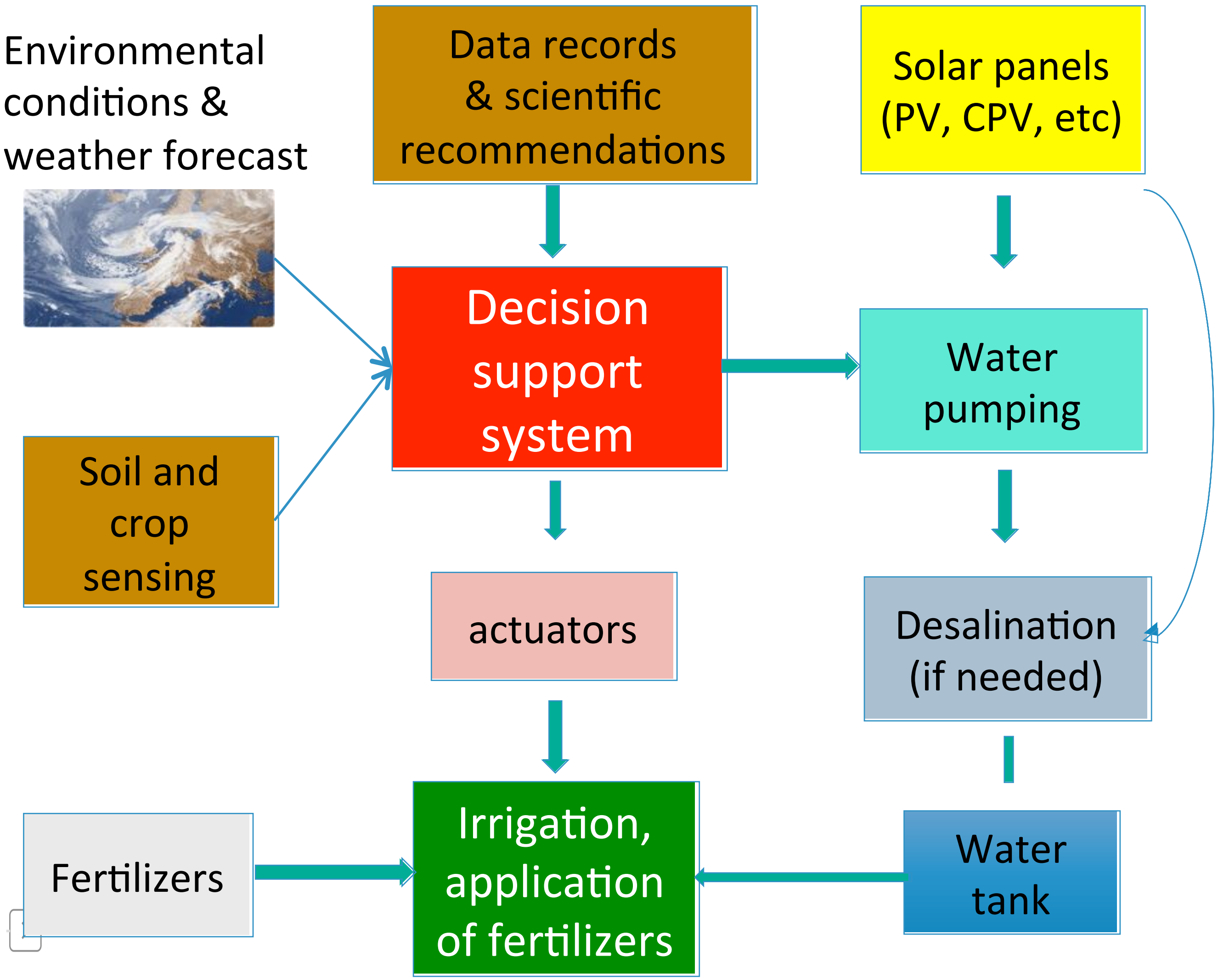
RFID-based luggage sorting solution (RFID-Sort)

- Objective: Develop and deploy an RFID-based system to optimise luggage sorting at Mohamed V airport

- Funded by CNRST
- Starts 2016
- Duration: 3 years

# Smart Agriculture: SolarSYS project

- Solar Powered Smart Irrigation System (SolarSIS)



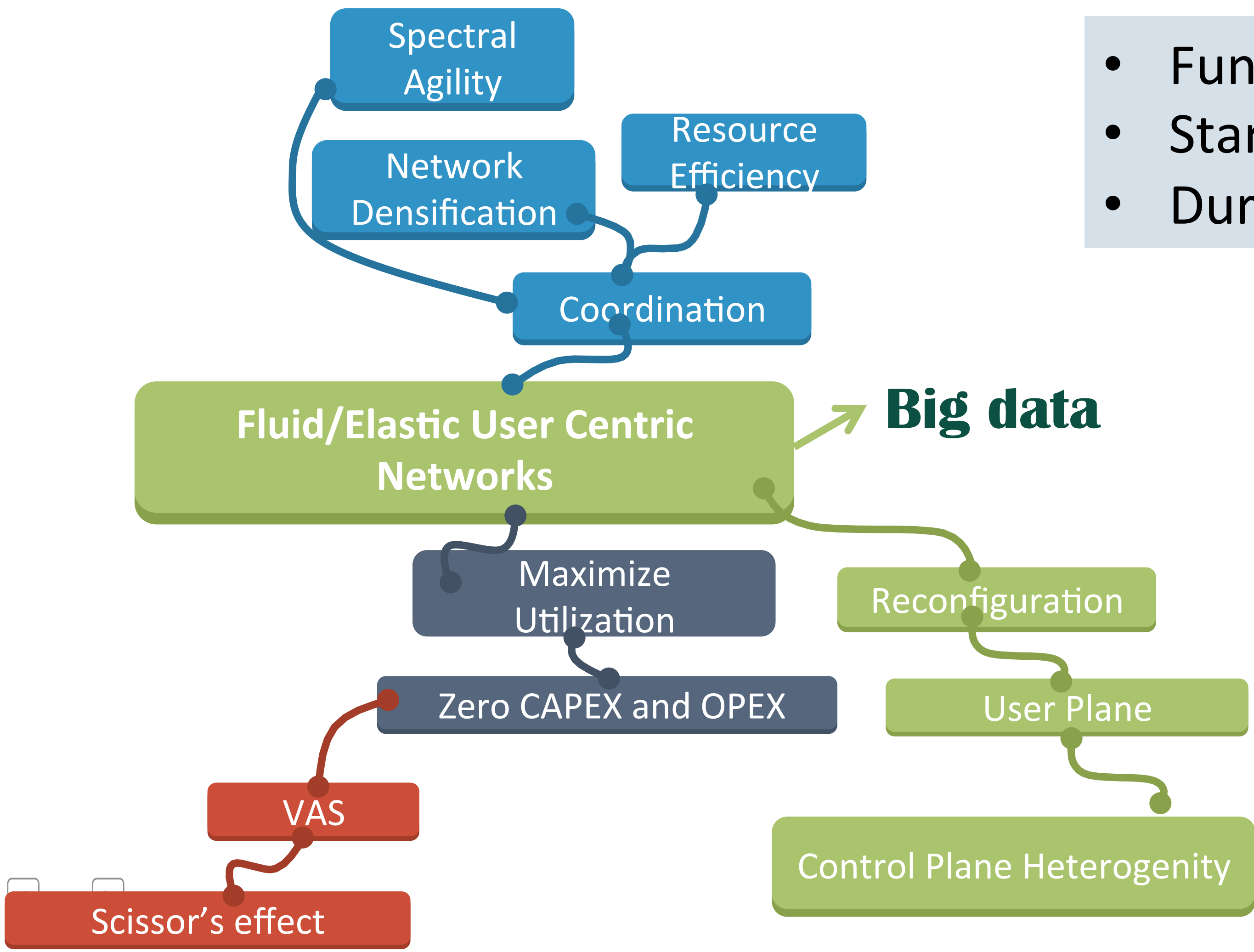

- Submitted to USAID (invited to submit the full proposal)

Partner:

MISSISSIPPI STATE UNIVERSITY

# Mobile broadband: GreenNet project

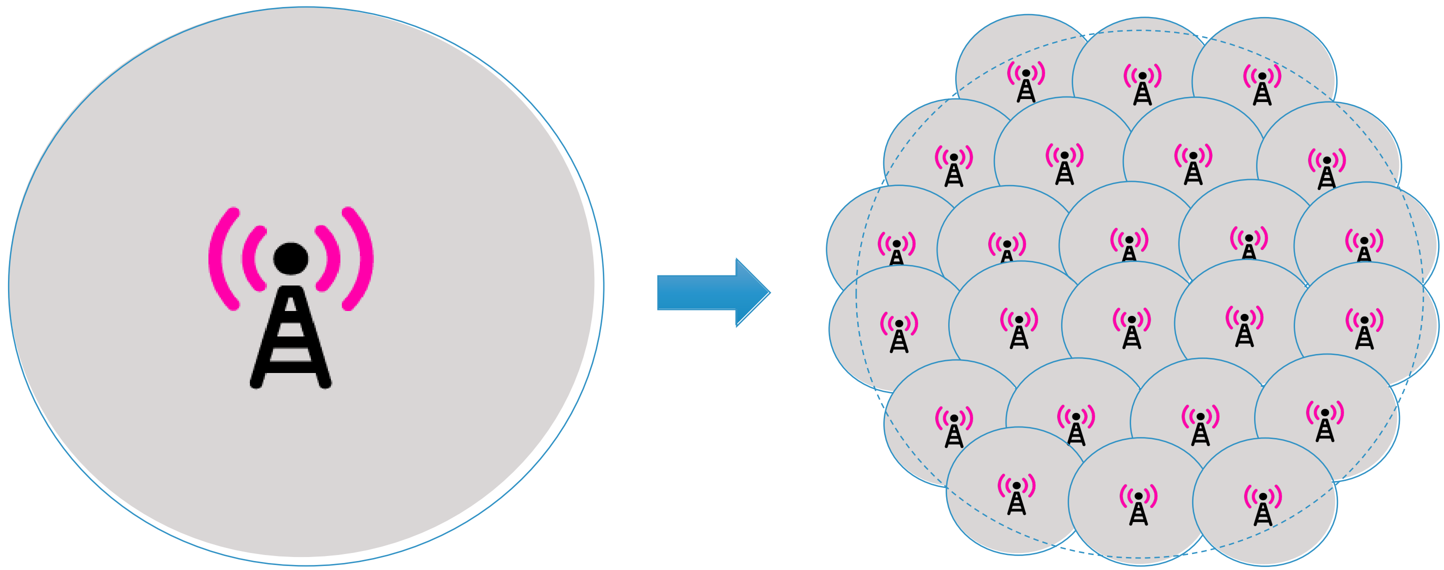
## Green 5G cognitive cellular networks (GreenNet)




- Funded by US Army
- Started 2014
- Duration: 3 years

Partners:

# Network densification



Enabling Pervasive Communication for Smart Cities

Large cell coverage

Small cell coverage

# Network densification

## Potential

Typical user's throughput:

$$R = m\left(\frac{B}{n}\right)\log_2\left(1 + \frac{S}{I+N}\right)$$

$B$: Bandwidth

$n$: load factor (# users/cell) ( $\searrow$ with smaller cells)

$m$: spatial multiplexing factor ( $\nearrow$ with MIMO)

$S$: received signal power ( Tx power $\searrow$ with smaller cells)

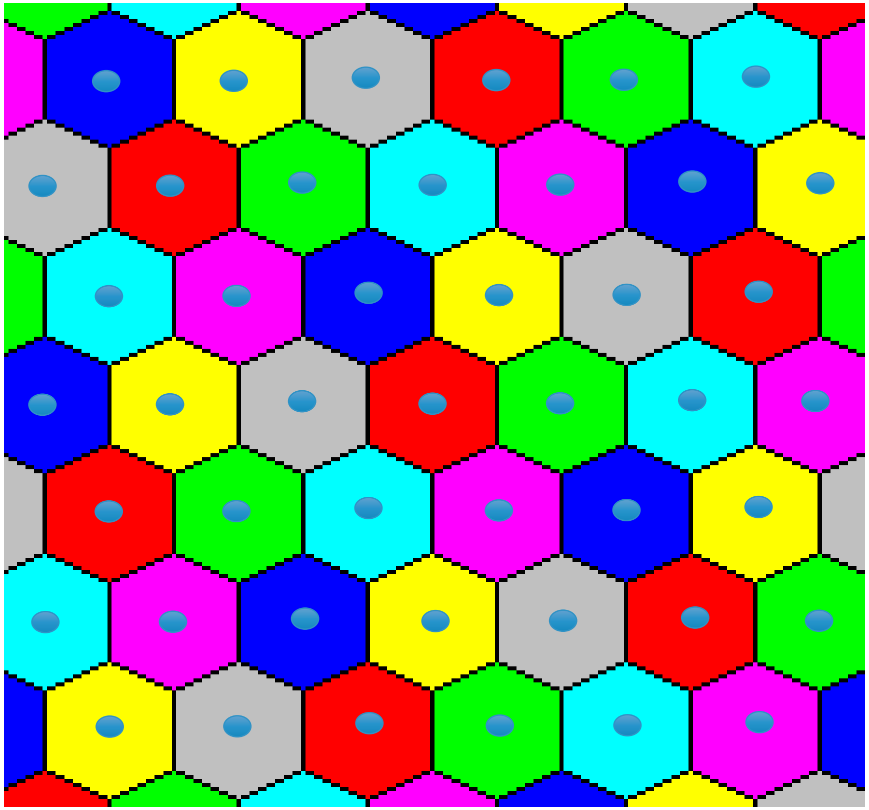
$I$: aggregate interference ( $\nearrow$ with smaller cells)

$N$: noise power (masked by $I$ with smaller cells)

# Network densification

## How to model base station distribution?

Traditional modeling



# Network densification

## How to model base station distribution?

**Worldwide Base Station Locations Available via OpenCellID**

Base station distribution in Taipei City, Taiwan, shown on Google Map. Blue Δ's are the locations of base stations

C.–H. Lee, C.–Y. Shihet, and Y.–S. Chen, "Stochastic geometry based models for modeling cellular networks in urban areas", Springer Wireless Netw., 10 pages, Oct. 2012.
Research Center for Information Technology Innovation, Academia Sinica, Taipei, Taiwan.

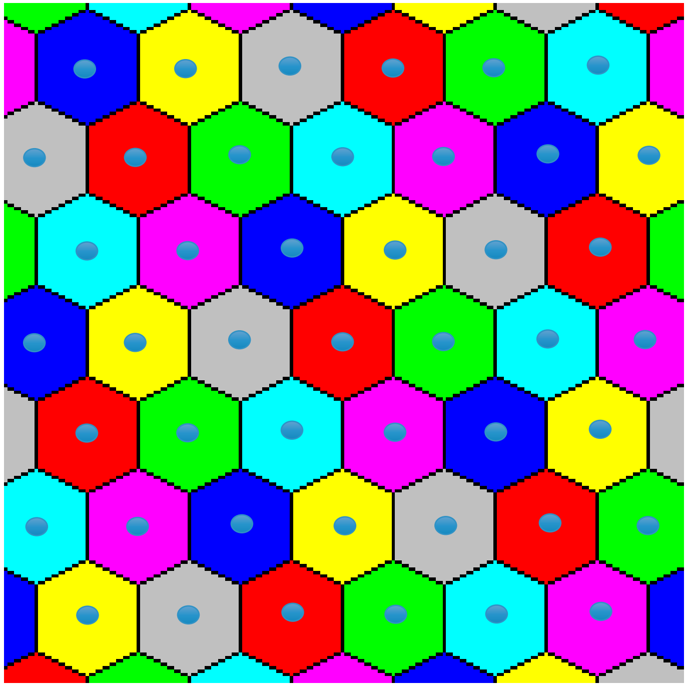
Open source project OpenCellID: http://www.opencellid.org/

# Network densification

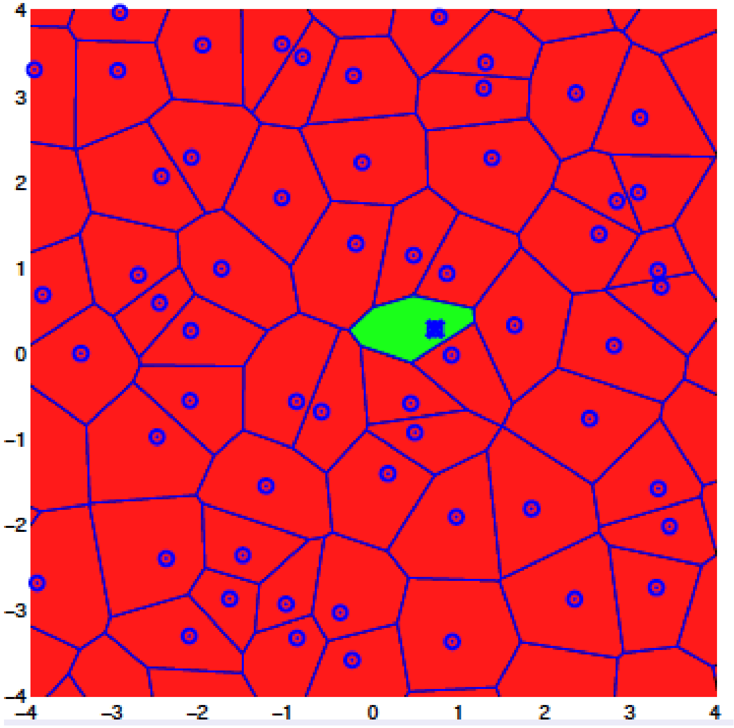
## How to model base station distribution?

An emerging tractable approach: Stochastic Geometry

Traditional grid model

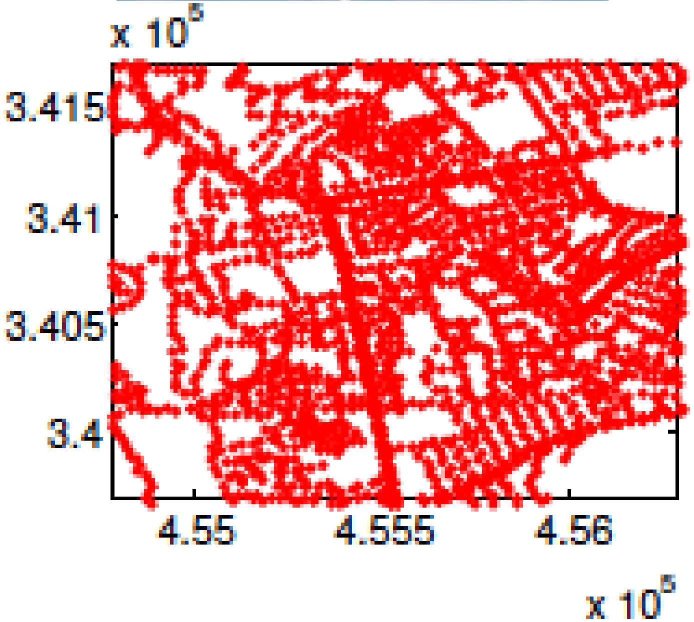


Random spatial model (PPP)



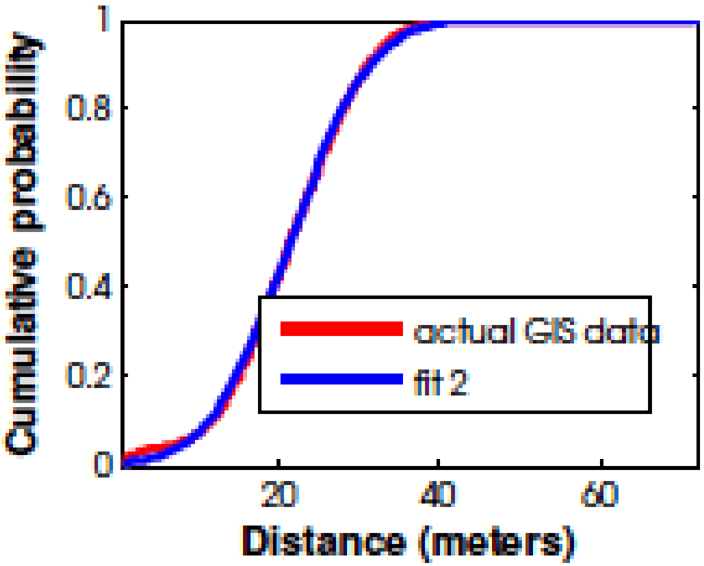
# Network densification

## PPP: particularly useful for dense networks




(a) Snapshot of a point pattern formed by Lamp posts in Nottingham City.

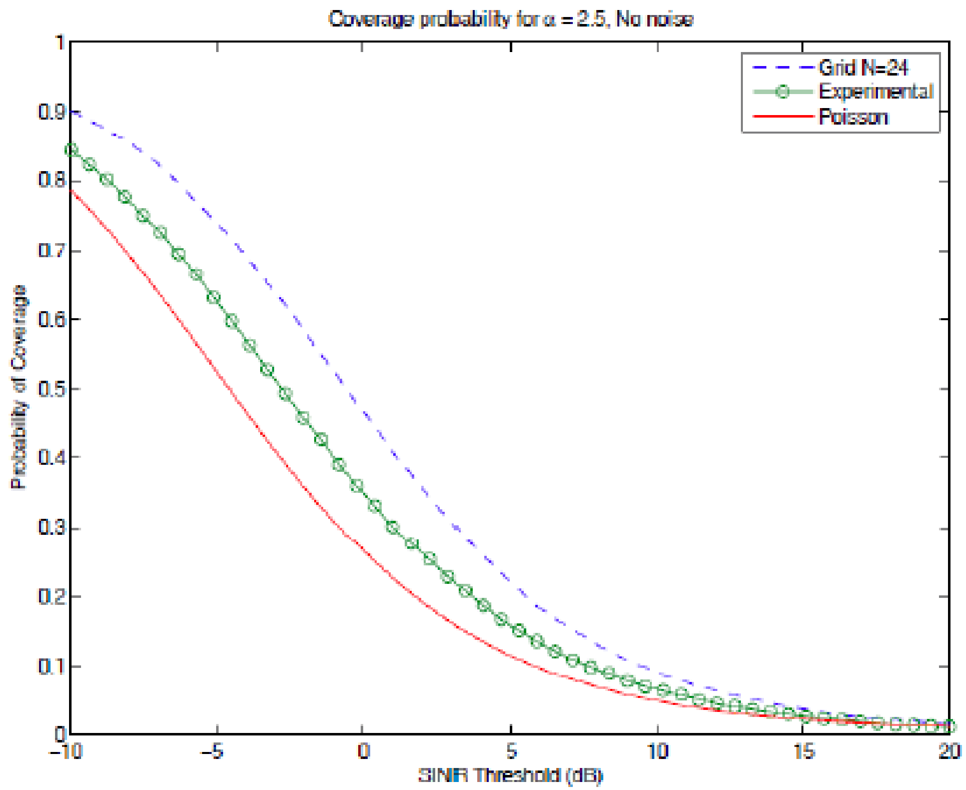
Clark-Evans test




(b) Nearest Neighbor Distance Distribution for Poisson point process vs. the Measured Data, i.e., $\lambda_{LP} = 0.48 \times 10^{-3}$.

# Network densification

## PPP-based performance provides a lower bound for the coverage




J. G. Andrews, F. Baccelli, and R. K. Ganti, "A Tractable Approach to Coverage and Rate in Cellular Networks", IEEE Trans. Commun., vol. 59, no. 11, pp. 3122–3134, Nov. 2011. 23

Analogy: Rayleigh fading model provides a lower bound for coverage/link budget

# Network densification

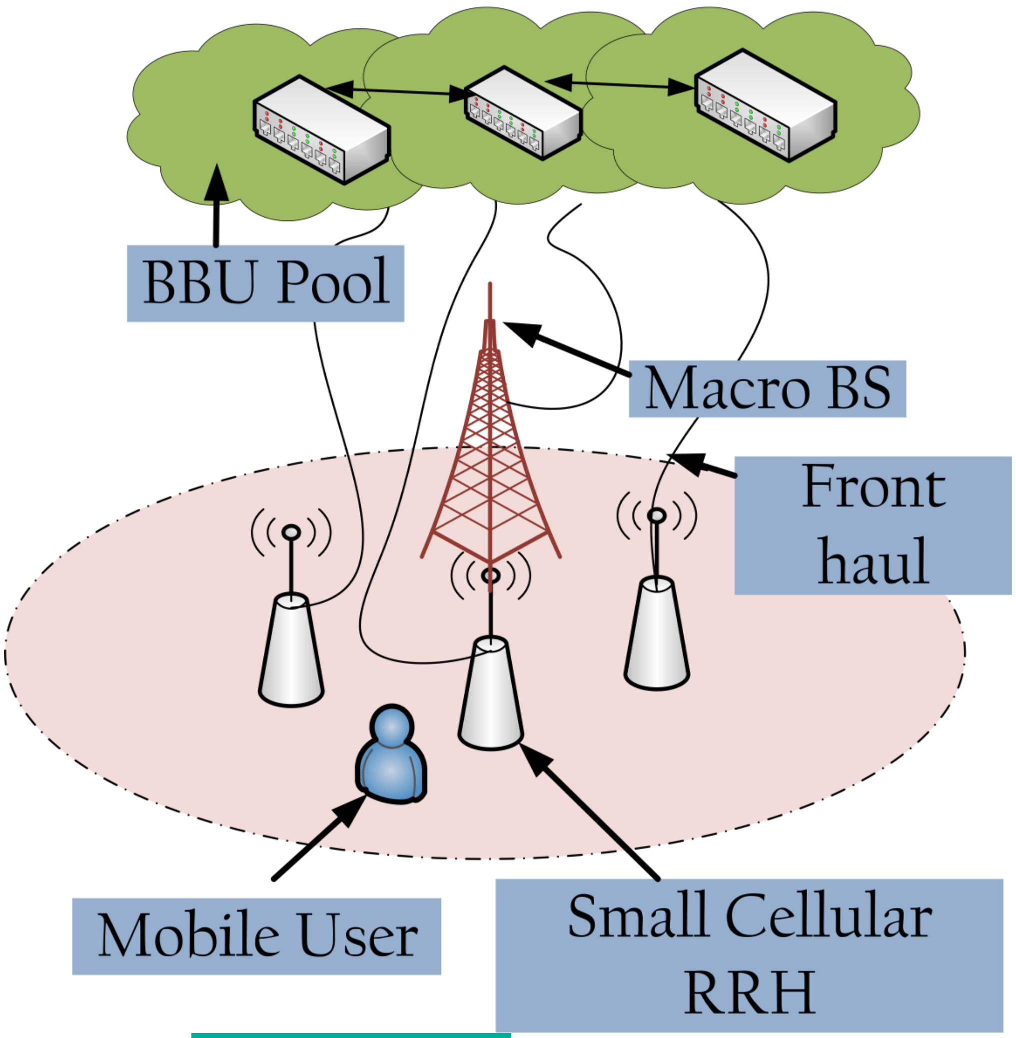


## Backhaul challenges

- Backhaul networking
  - Many outdoor small cells sit on lampposts and street furniture, so bulk of deployment need microwave (including mmwave) links
  - Absence of direct connection to a central aggregation site (CAS)
  - So, because of real estate issues and connectivity issues, small cells will mainly be connected to each other before reaching the CAS. So, aggregation needed along the way, not just at CAS.
- Synchronization
- Interference management
- Backhaul bottleneck

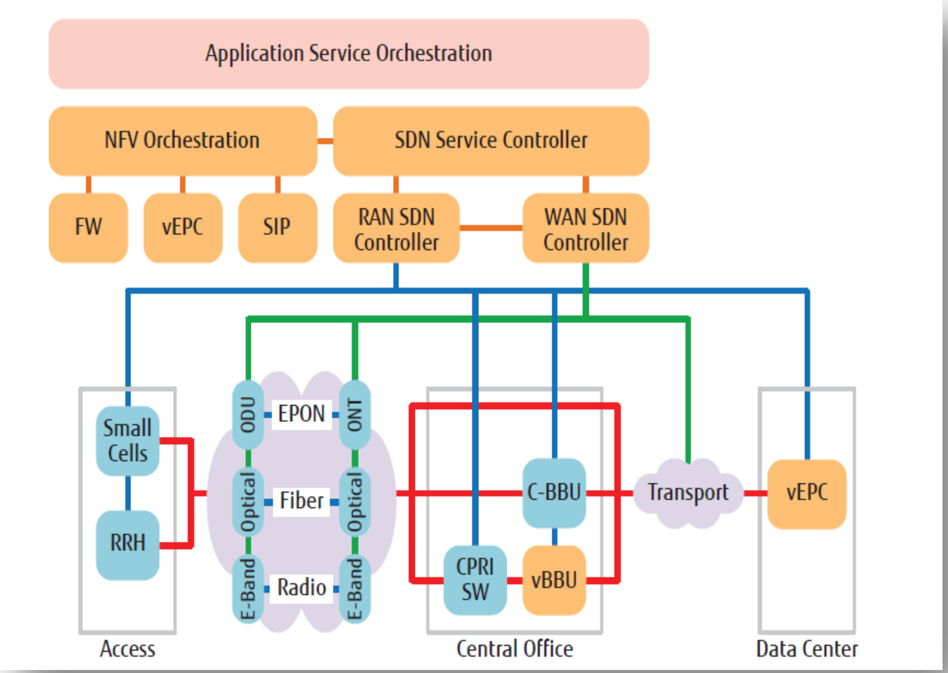
# Cloud Radio Access Networks





# Cloud Radio Access Networks

- On demand capacity addition;
- Energy saving:
  - Centralized coordination;
  - Centralized load balancing;
  - Centralized Sleep scheduling;
- BBU pool central air conditioning
- Efficient coordination:
  - Interference;
  - Mobility and Handover;



IEEE Communication Magazine, July 2015



# Solar Energy Empowered 5G Cognitive Metro-Cellular Networks

*Syed Ali Raza Zaidi, Asma Afzal, Maryam Hafeez, Mounir Ghogho, Desmond C. McLernon, and Ananthram Swami*

## Natural vs. Synthesized Sources

| Source | Irradiance | |
|---|---|---|
| Solar | Outdoor (solar noon) | 100 mW/cm$^2$ |
| | Outdoor (cloudy) | 10 mW/cm$^2$ |
| | Indoor | 10–100 µW/cm$^2$ |
| Wind | 10 miles Class 7 | 12 mW/cm$^2$ |
| Thermo-electric | 5°C gradient | 40 µW/cm$^3$ |
| RF | ambient | 1 µW/cm$^2$ |
| Vibrations | Piezoelectric-shoe inserts | 330µW/cm$^3$ |
| | Electrostatic @ 105 Hz | 0.021µW/mm$^3$ |
| | Electromagnetic @ 10 Hz | 184 µW/cm$^3$ |
| | Electromagnetic @ 52 Hz | 306 µW/cm$^3$ |

**Table 1.** Power densities of energy harvesting technologies.

IEEE Communication Magazine, July 2015



# Solar Energy Empowered 5G Cognitive Metro-Cellular Networks

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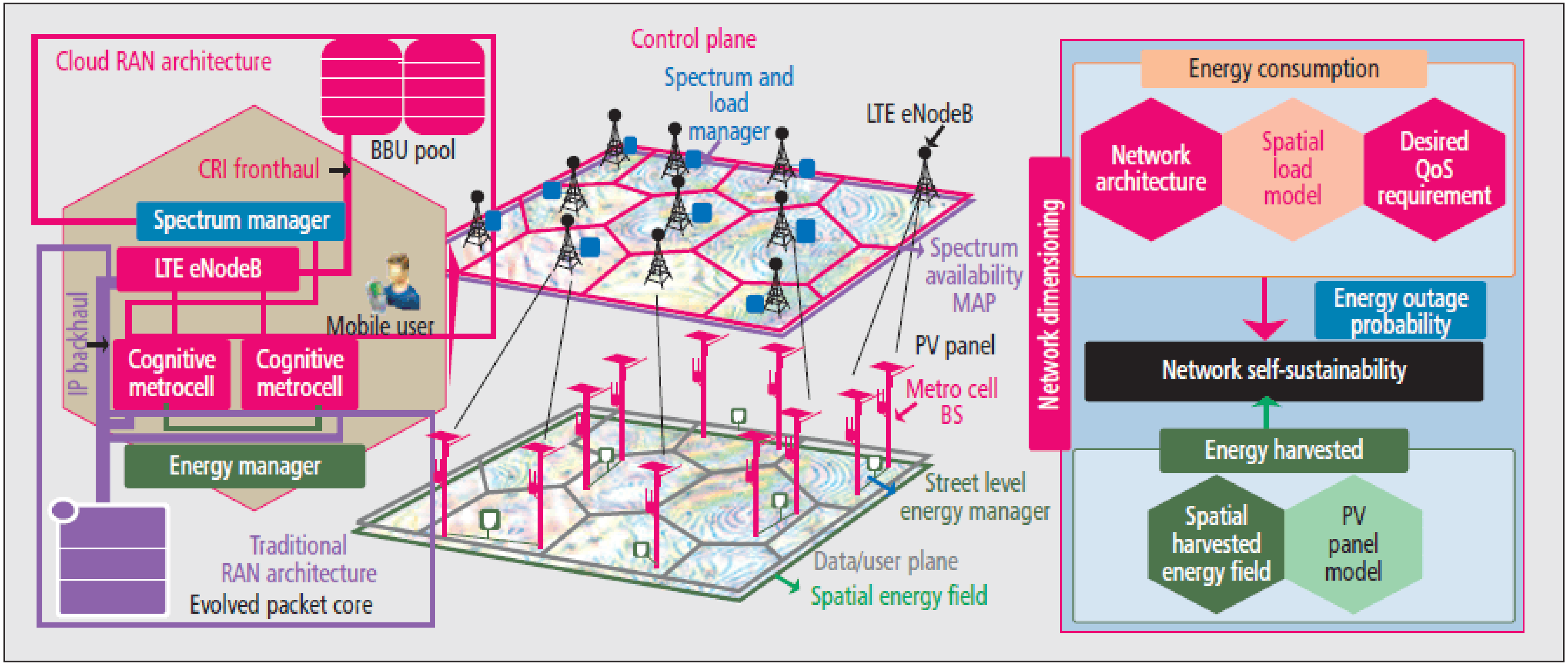


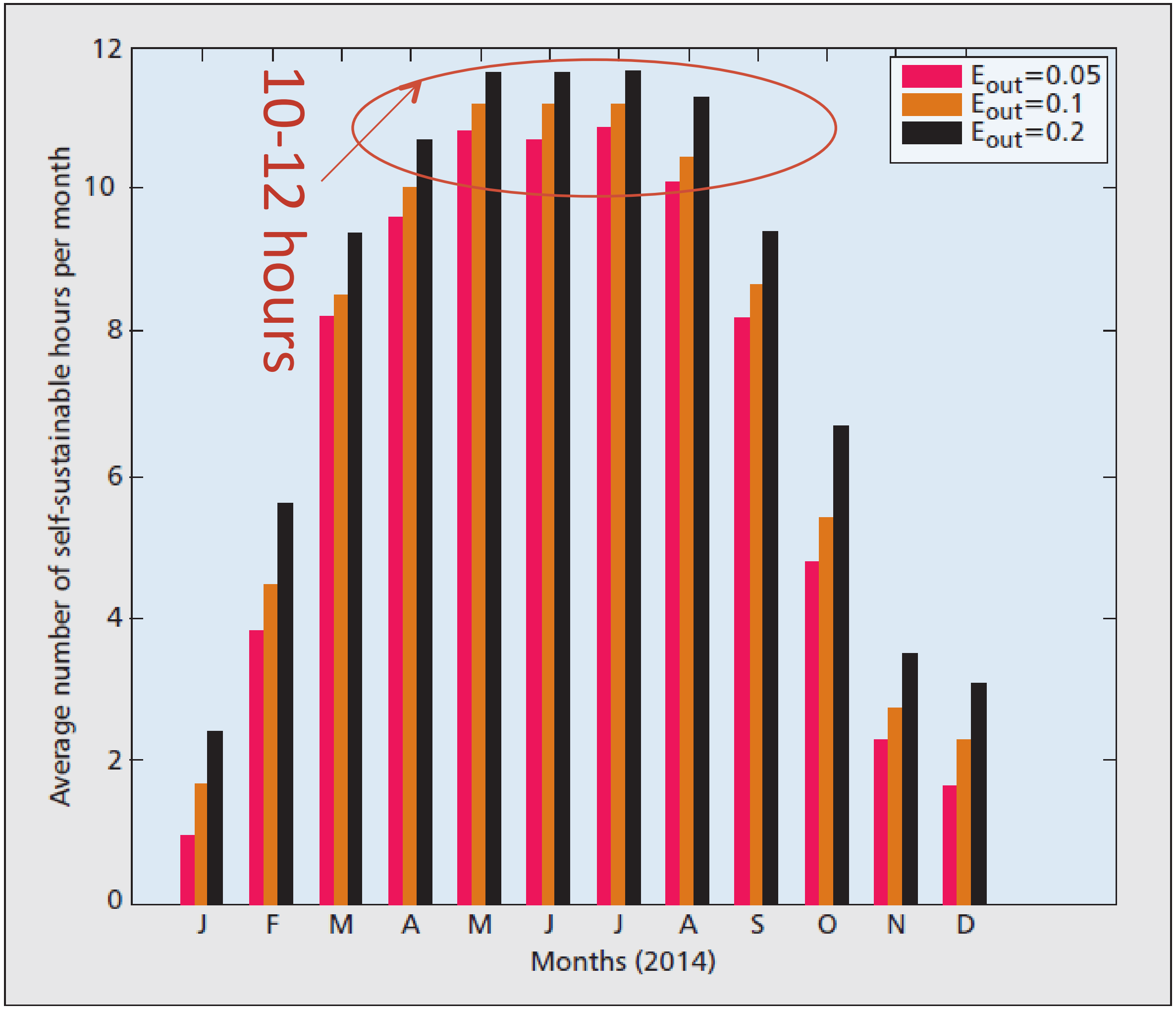
# Spatio-temporal Load Model

- Variation in number of MUs: half sine model with respect to the number of hour of the day.
  - Empirical traffic measurements
  - User density has a predictable pattern, i.e., it reaches at a minimum value around 4-5 a.m. rising steadily thereafter till the evening to a peak value and decaying afterward.
  - Weekdays vs. weekends;
- Load model:
  - Traffic variation: Half sinousoid model, i.e.,

$$\lambda_U(t) = \lambda_U \underbrace{\left(\kappa_5 - \kappa_6 \sin\left(2\pi \frac{(t-\phi)}{24}\right)\right)}_{U(t)}, \tag{1}$$

    such that $\kappa_5$ and $\kappa_6$ are traffic related constants which lie in interval $[0,1]$ so that $max\,|U(t)| = 1$.
  - Spatial distribution: HPPP with $\lambda_U(t)$;
  - Association: Nearest Neighbour, i.e., forming Voronoi tessellation.

# Network Self-Sustainability?



# Conclusions

- CRs with energy harvesting →Promising solution for connectivity in smart cities.
- Opportunistic energy harvesting is key enabler for "green communication".
- Both temporal and spatial dynamics of the solar energy field and the mobile user traffic are critical in shaping the network-wide energy requirement.
- From the case study, a metro-cellular network is self-sustainable in terms of energy for around 3-12 hours of a day depending upon the time of the year.
- The dynamics and randomness in energy state can be exploited in future to attain energy aware load balancing and interference coordination.

# Thank you

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