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Complex Networks: Study and Performance Evaluation with Hybrid Model for Wireless Sensor Networks

Vincenzo Curia, Mauro Tropea, Peppino Fazio, Salvatore Marano

SPEAKER:
Peppino Fazio

5th May 2014 – ENG105 – Session CN3

PRESENTATION LAYOUT

- Wireless Communications Introduction
- Overview on Complex Networks (CNs)
- CN modeling
- Hybrid model proposal
- Simulation analysis
- Conclusions

PROPOSAL SUMMARY

- A new modeling proposal for WSNs (Ad-hoc in general), in order to consider them as CNs

- Introduction of the hybrid model concept;

- Evaluation of the introduced enhancements in terms of Clustering Coefficient (CC) and Path Length (L).

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WIRELESS NETWORKS

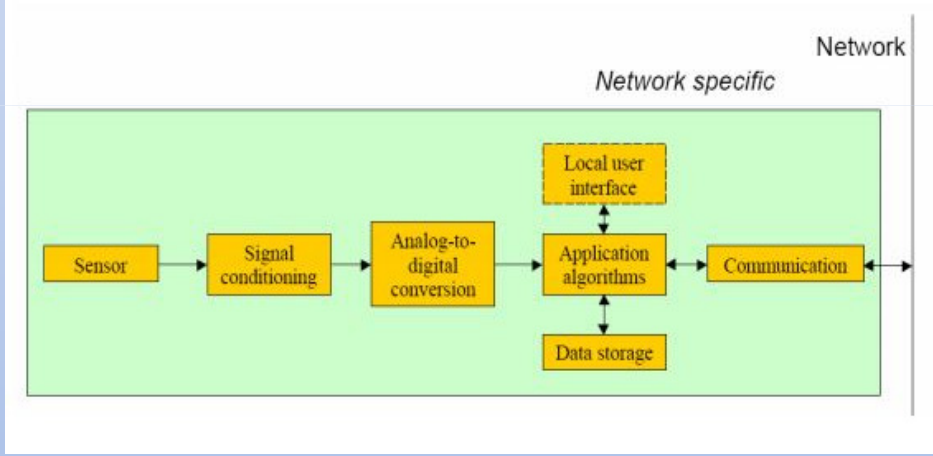
A brief overview of the technologies that have been considered in our work

WIRELESS COMMUNICATIONS

- In wireless networks, mobile nodes can access the available resources without needing of cables, only by using radio waves or infra-red frequencies;
- **Advantages:** as known, this approach leads to a high grade of mobility within the covered area, with a consequent good level of flexibility, if compared with wired networks;
- **Disadvantages:** on the other hand, exploiting radio or infrared waves brings to a lower transmission rate and high interference levels, if compared with wired networks;
- The most known WLAN standard has been introduced in 1990, when the IEEE created the 802.11 commitee.

WIRELESS COMMUNICATIONS
(SHORT-RANGE)

➢ The term ***Wireless Sensor Network*** (WSN) is referred to a particular network, characterized by a distributed architecture and a set of autonomous devices, able to communicate with each other, while picking up environmental informations.



➢ *Application fields:* Industrial, agriculture, health, military and traffic app.
➢ Advantages: Scalability, low costs, simplicity of installation.
➢ *Disadvantages*: Short coverage range, energy issues.
➢ *Standards:* **ZigBee** (from layer 3) and IEEE 802.15.4 (PHY & MAC).

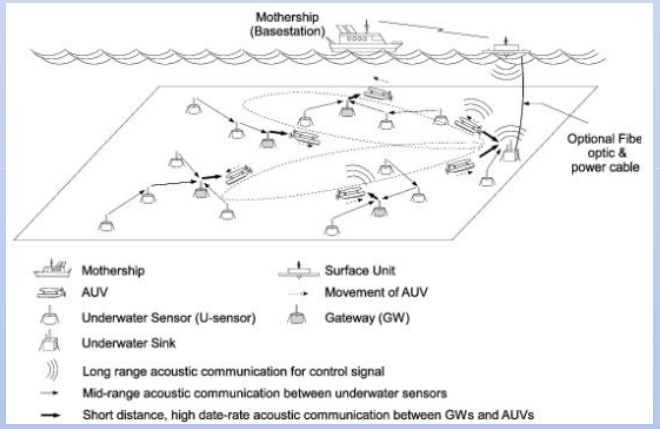
WIRELESS COMMUNICATIONS
(SHORT-RANGE)

- **ZigBee** is a standard, for a high level communication protocols used to low-power WPAN communications;
- **ZigBee** is based on IEEE 802.15.4 standard;
- **ZigBee** and IEEE 802.15.4 operates in the Industrial, Scientific and Medical (ISM) radio bands: 868 MHz in Europe, 915 MHz in the USA and Australia and 2.4 GHz in most jurisdictions worldwide;
- **ZigBee network layer** natively supports both star, tree mesh networks;
- **ZigBee** transmission distances range from 10 to 1500 (ZigBeePRO) meters and line-of-sight;

WIRELESS COMMUNICATIONS

SENSORS NEW POSSIBLE APPLICATIONS (2 EXAMPLES)

➢Creatures tracking, in underwater sensor networks:



➢Through-wall watching, only by analyzing EM fields:

WIRELESS COMMUNICATIONS

(LONG-RANGE) – HSPA/LTE (3G/4G) OR Wi-Fi

- **High-Speed Packet Access (HSDPA)/Long Term Evolution (LTE)**, are mobile communications protocol;
- High Speed communications protocol, but require large power to provides high-speed wireless traffic transfer to the Internet;
- Support MIMO transmission;
- They are widely used today, so their price is extremely low;
- **Wi-Fi**: it is based on IEEE 802.11a/b/g/n standards.

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COMPLEX NETWORKS (CNs)

A brief overview and why CNs in TLC systems

COMPLEX NETWORKS

- Before giving a definition let us consider some network topologies:

- **Regular Networks**: each node is uniformly deployed into the network and it has the same number of connections (so the same grade);

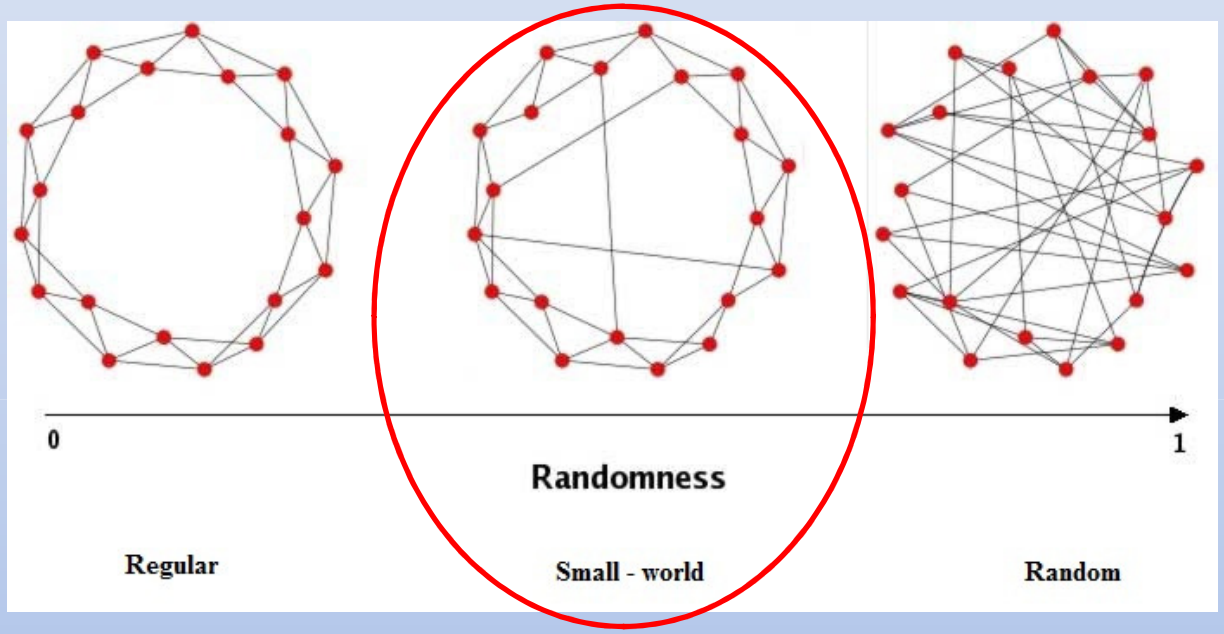
- **Random Networks:** Connections between nodes are created in a totally randmom way.

- **Real Networks examples**: Biological, Knowledge, Social, Neural, Artificial; their nature is different and they do not belong neither to regular, nor to random networks.

- There is not a formal definition for CNs, but the most of the existing (real) networks can be considered as CNs, with high distribution degree, high clustering coefficient, nodes associativity, hierarchical structure and not-trivial topology.

- In 1998 Watts and Strogatz introduced the **Small World (SW)** networks: they have the same topological properties of the real networks, such as high Cluster Coefficient (CC) and a reduced average path length.

COMPLEX NETWORKS



➢ **CC** of node n_i: indicates the tendency of two nodes, neighbors to a common one n_i, to be connected each other: $c_i=[e_i/k_i(k_i-1)/2]$; CC is the average on all c_i;

➢ **Node's grade:** number of edges connected to the node: $k_i=\Sigma_i a_{ij}$;

➢ **Average path length**: average length of the shortest paths, evaluated for each couple of nodes.

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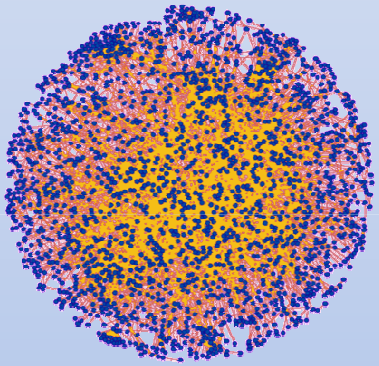
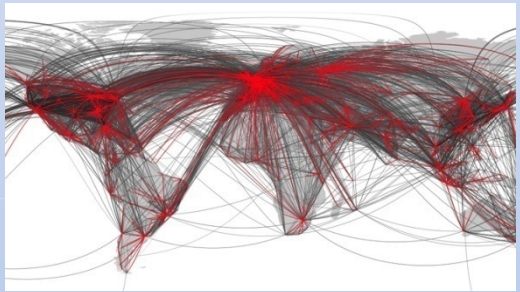
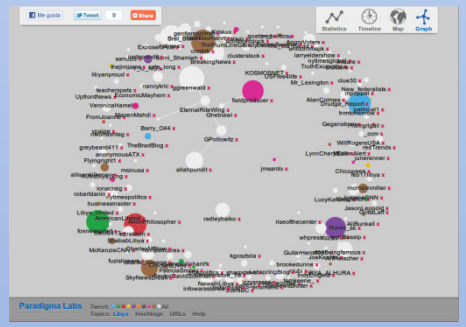
COMPLEX NETWORKS
(Some real examples and topologies)



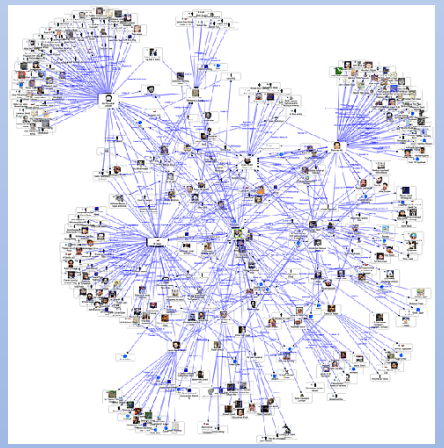
Generic CN1



Social networking (FB)



Social networking (TW)



Generic CN2

COMPLEX NETWORKS (BENEFITS)

Modeling a real network in a complex one has many advantages:

- All networks present in nature are complex networks (so, more reality is given to the model);

-Scalability and flexibility: easy addition and/or removal of new nodes, always respecting the definition of CN;

- Fault Tolerance: CN are strongly connected ($C \rightarrow 1$), so the fall of a link does not change the performance of the network;

- It is not so easy describing the interactions between nodes only by edges and weights (so by a traditional graph), so CN approach is suitable;

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PROBLEM FORMULATION AND MODELING

Description of the considered environment and proposal

PROBLEM FORMULATION (MODELING)

- **How to model an existing network as a SW network**;
- Finding a new solution, based on the already existing studies;
- The known techniques are:

-**Data Mules** (or ferries) introduction: with the main aim of introducing shortcuts;

-**Link re-wiring**: starting from a regular network, deleting existing edges by creating random connections between other nodes;

-**Kleinberg modeling**: adding edges to each node, choosing the destination randomly;

-**Dual-radius modeling**: considering special nodes with higher coverage range.

Our proposal: A New Hybrid modeling, based on Data Mules and Dual-radius.

PROBLEM FORMULATION (MODELING)

➢**Our proposal tends to decrease the Average Shortest Path Length (L) and increasing the Clustering Coefficient (CC) in a real telecommunication network;**

➢L must be ≈ 6, according to Milgram's Experiment;

➢CC must → 1, according to CN definitions.

WHY HYBRID MODELING

-**Data Mules** introduces shortcuts, to decrease L parameter;

-**Dual-radius** creates links between geographically separated clusters to increase CC parameter;

Our proposal: A New Hybrid modeling, based on Data Mules and Dual-radius.

PROBLEM FORMULATION (MODELING)

IN PARTICULAR:

-**Hybrid nodes** combine two efficient techniques, Data Mules and Dual-Radius;

-**Data Mules** act as bridging nodes, allowing two or more communication networks to create an aggregate network;

-**Dual-radius**, in the considered case, consists in ZigBee and 3G (or 4G).

WE EXPECT THAT:

-**Data Mules** create long-ray ferries for introducing shortcuts, with a consequent decreasing of the Average Shortest Path (L);

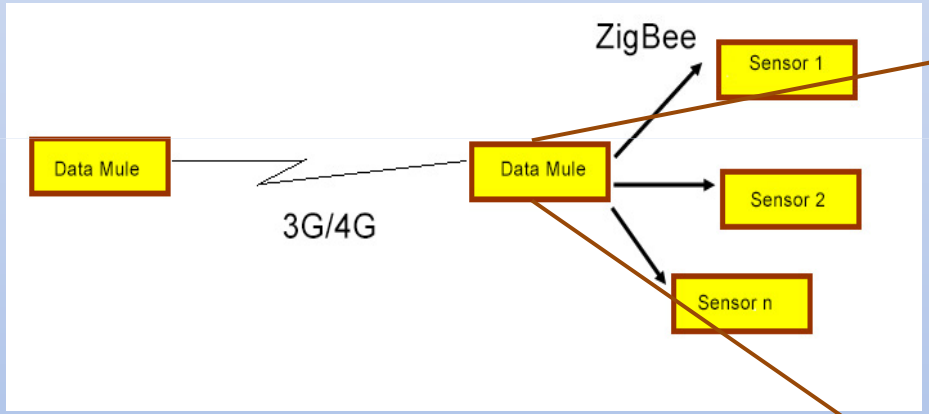
-**Dual-radius** creates links between geographically-separated clusters, with a consequent increasing of CC;

Our proposal: A New Hybrid modeling, based on Data Mules and Dual-radius.

PROBLEM FORMULATION (MODELING)

An example

➢ There are many studies on the development of the connectivity between Zigbee (or IEEE802.11) and UMTS (or 3G/4G) networks and the creation hybrid nodes:



➢There are some products on the market already (for 3G/WLAN connectivity) and some prototypes for 4G and Zigbee interfacing. More details can be found at:

-http://www.dlink.com/-/media/Consumer_Products/DWR/DWR%20730/Datasheet/DWR_730_B1_Datasheet_EN_EU.pdf/

-http://ijircce.com/upload/2014/icgict14/417_1712.pdf

PROBLEM FORMULATION (MODELING)

- In this work we are studying the effects of the introduction of new hybrid nodes into a sensor network;
- New added nodes can follow pre-established trajectories or random ones, with dynamic speeds;
- As we will see, there will be an upper bound for the introduction of new nodes, beyond which no more enhancements are obtained; this limit is strictly related to the extension and density of the graph G=<V, E>:

$$DENSITY = \frac{2 \cdot \| E \|}{\| V \| \cdot (\| V \| - 1)}$$

- Many studies in literature demonstrates how the insertion of new nodes after a threshold do not bring enhancements into the system (Milgram's experiment).

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SIMULATION AND PERFORMANCE EVALUATION

Description of the developed tool and main results

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SIMULATION AND PERFORMANCE EVALUATION

➢A Multi-thread Java simulator has been developed, able to evaluate the behavior of a WSN with and without special nodes;

➢A local geographical area of south Italy has been considered (Corigliano Calabro – South Italy), with different extenstions:

➢ Different simulations have been performed in the scenario, evaluating the density, the average path length (with and without special nodes) and the clustering coefficient.

SIMULATION AND PERFORMANCE EVALUATION

- Sensor nodes are placed randomly into the network and follow the available roads; we hypotesize that they move with related cars;

- Special hybrid nodes are placed into buses and follow the red ring road; for coverages, we considered 35 meters for sensor nodes, 150 and 35 meters for hybrid nodes (results have been shown for IEEE802.11n for long-range communications);

- Simulations have been carried out by varying: extension area and number of hybrid data-mules (the number of normal sensor nodes has been fixed);

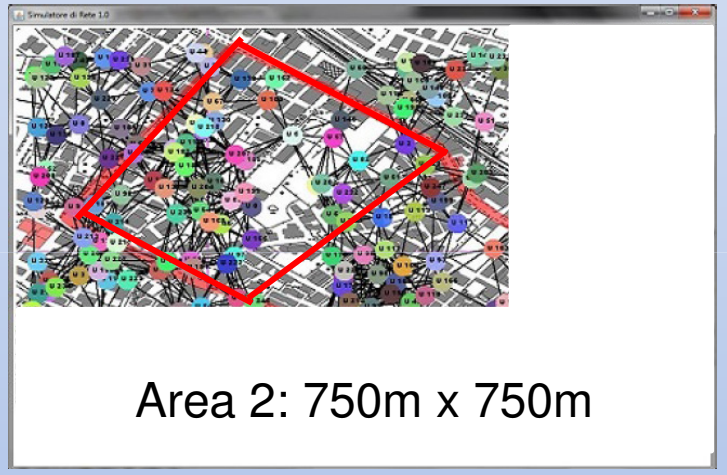
- Except for the path for hybrid nodes, sensors mobility has been generated through C4R (City 4 Roadmaps) mobility generatore, based on **OpenStreetMap** and **SUMO** (Simulator of Urban MObility);

- Paths are considered from one node to each other one.

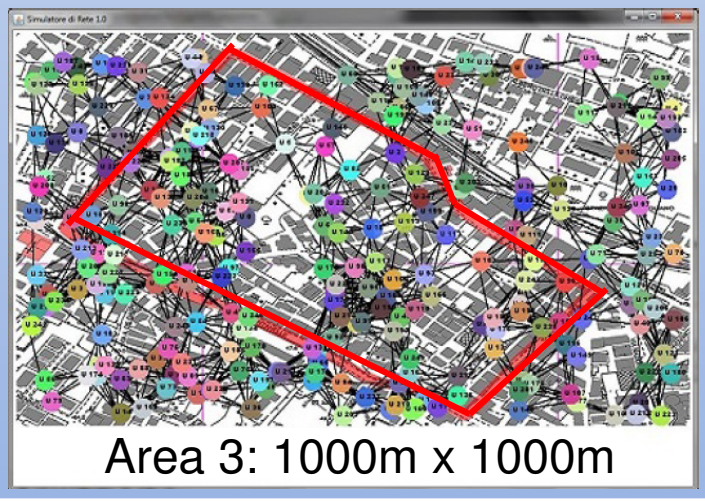
SIMULATION AND PERFORMANCE EVALUATION

➢Different area extensions have been considered:

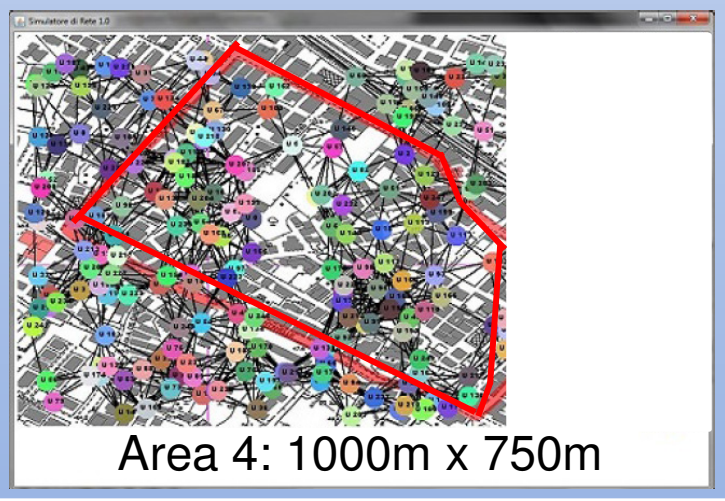
Area 1: 500m x 500m



Area 2: 750m x 750m



Area 3: 1000m x 1000m



Area 4: 1000m x 750m

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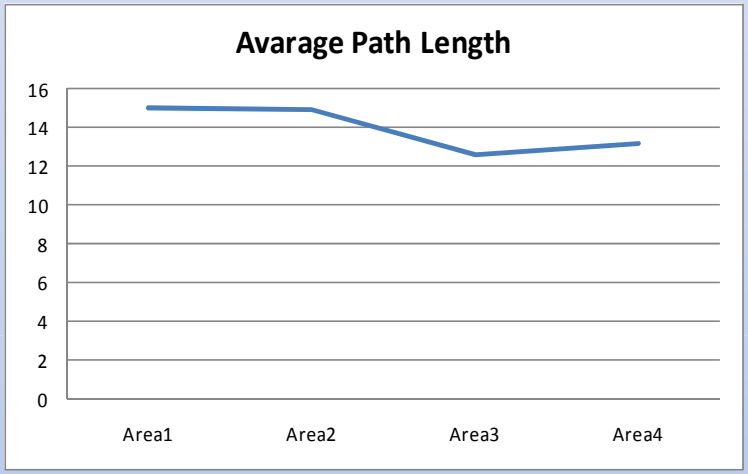
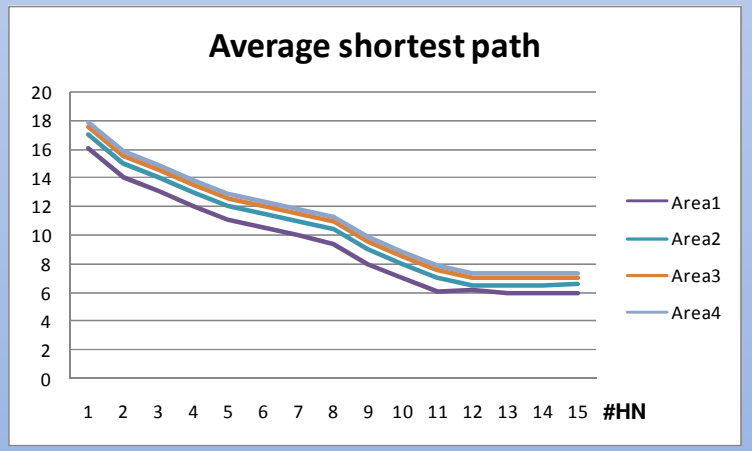
SIMULATION AND PERFORMANCE EVALUATION



This figure on the left represents only the typical values of the average path length (from 12 to 15 nodes) for each considered scenario. No hybrid mules are considered.

The figure on the right shows that there exists an upper limit of the number of special nodes to be included within a network of ad-hoc sensors. It is clear, furthermore, that the variation of the average paths L, is very similar in the different scenarios.



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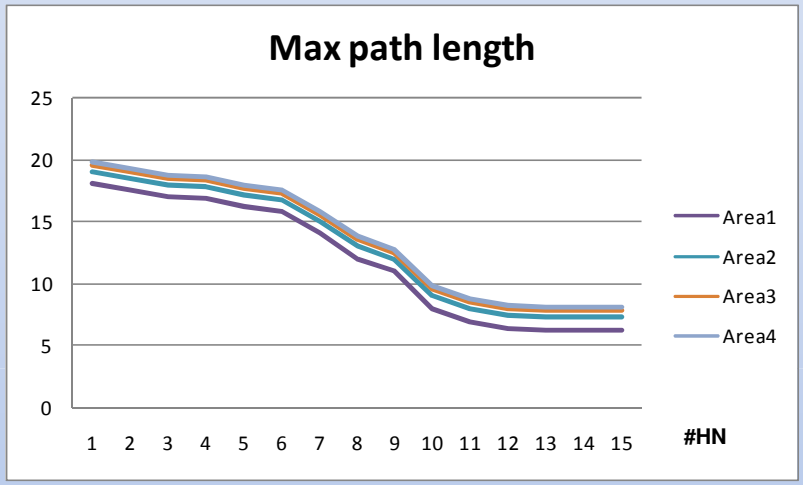
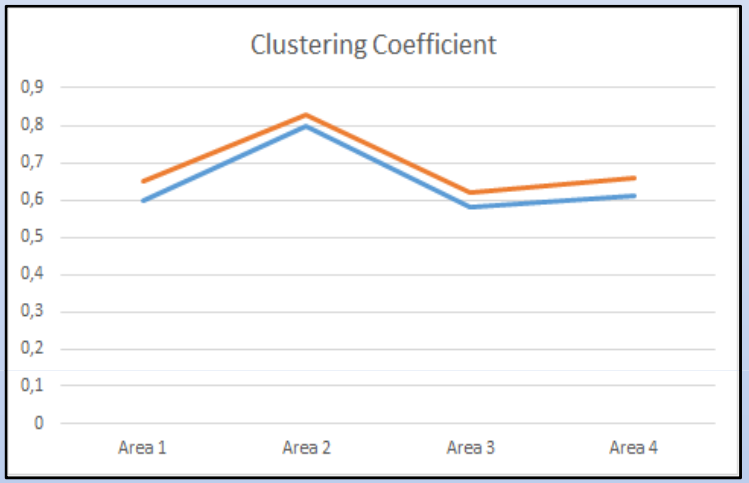
SIMULATION AND PERFORMANCE EVALUATION





The same trend is obtained for the maximum path length of the considered scenario.

Special hybrid model, once applied, tends to slightly increase this value compared to the one of the original network (blue). The change is about one percentage point. As stated before, a value of CC near to 1 indicates a high connection between neighboring nodes (obviously, in a fully connected network, such value is equal to 1).

CONCLUSIONS

-In this paper a new model for WSNs and CNs has been proposed;

-By considering any existing, real and appropriately modeled, network the hybrid model significantly reduces the average length of the shortest path, and increases (even if only slightly) the medium cluster coefficient, thus obtaining those characteristics that mark the complex networks as small-world;

- Modeling a network as a CN may be advantageous, in fact, reducing the shortest path, the communication within the network is faster, reducing latency and vital parameters such as RTT;

-Data Mules are also able to perform load balancing in the various paths of the network, avoiding overloads and preventing any performance degradation. Increasing the clustering coefficient also increases the resistance to network faults, in case of a fall of one or more links.

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