Self-organizing behavior of Wireless Ad Hoc Networks

T. Raghu Trivedi, S. Giri Nath

Abstract—Self-organization is a great concept for building scalable systems consisting of huge numbers of subsystems. The primary objectives are coordination and collaboration on a global goal. Until now, many self-organization methods have been developed for communication networks in general and ad hoc networks in particular. Nevertheless, the term self-organization is still often misunderstood or misused. This paper contributes to the ad hoc community by providing a better understanding of self-organization in ad hoc networks. The main contribution of this paper is a categorization of self-organization methodologies.

Index Terms— self-organization, ad hoc networks, wireless sensor network, ad hoc routing, network layer, medium access control, clustering.

1 INTRODUCTION

Self organization concerns organizing a set of mobile nodes with unique identifiers and wireless medium of communication into a connected network, which is able to do things like self-configure or self-organize. It concerns maintaining the structure when topological changes occur, for instance with respect to node failure, node motion or link failure. Self organization is very important in building scalable systems particularly systems such as MANETs which are decentralized and which is composed of typically large number of subsystems.

The primary objectives of self-organization include co-ordination and collaboration to achieve shared goal, achieve collaboration without central entity and improving the reliability, scalability and availability of the system. The availability is all about probabilistically ensuring that the system made available to the users for certain duration of time. The scalability concerns that how the system is going to perform when the number of nodes in the system is going to increase. The reliability is all about probabilistically ensuring that the system is overall going to behave reliably at all durations of time when it is suppose to operate. There are different design goals of self-organization in MANETs with respect to neighbor discovery, topology configuration and topology maintenance.

Self organization is a behavior that occurs in the nature and that has been inspired from different natural phenomena and has been adopted in network systems.

- *T. Raghu Trivedi, Sri Padmavathi College of Computer Sciences & Technology,Tiruchanoor. E-mail: tamirisa_t1@yahoo.com*
- *S. Giri Nath, Sri Padmavathi College of Computer Sciences & Technology,Tiruchanoor. E-mail: girisuddala@gmail.com*

In self organization there are patterns which emerge at the global level using only local information generated by interaction between lower level components. For example in case of MANETs, in local interactions between different nodes with in a particular area and together that information would scale up to the overall network system level and a pattern emerge from that.

Emergent behavior is another concept that comes very close when we talk about self organization. It basically is a behavior of a complex system that is generated by simple interactions between lower level entities in more than the sum of their behaviors. Thus self organization from a network perspective includes the set of algorithms and protocols that govern system behavior based on simple interaction between different nodes. For instance simple message exchange between neighbor nodes in a MANET that would lead to packet transmission form source node to sink node.

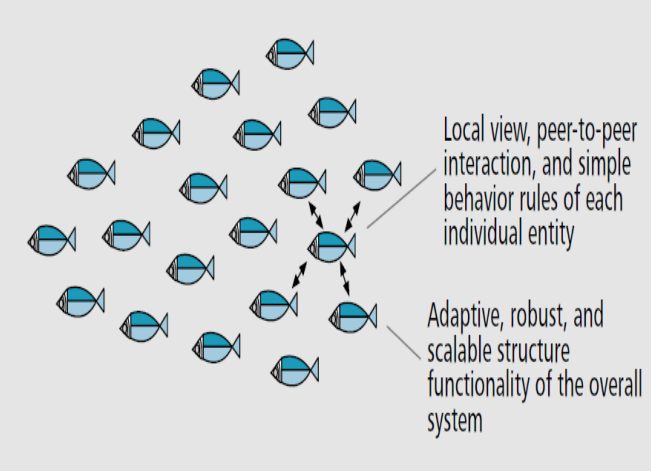

Fig. 1. Self-organization view of a system

Every node has local view about the behavior of peers and it can interact with the direct neighbors which are peers. These local interactions between nodes together would scale up to overall network system level and a pattern emerges from that.

2 SELF-ORGANIZED VS CONVENTIONAL NETWORKING

Self-organization approach uses the local properties and rules to achieve or approximate overall network functions and properties. In contrast the conventional, centralized approach uses global properties to achieve overall network functions. Self-organization approach uses the implicit coordination between different nodes to achieve overall network functions and properties. In contrast the conventional, centralized approach uses perfect coordination among nodes with centralized address assignment to achieve overall network functions.

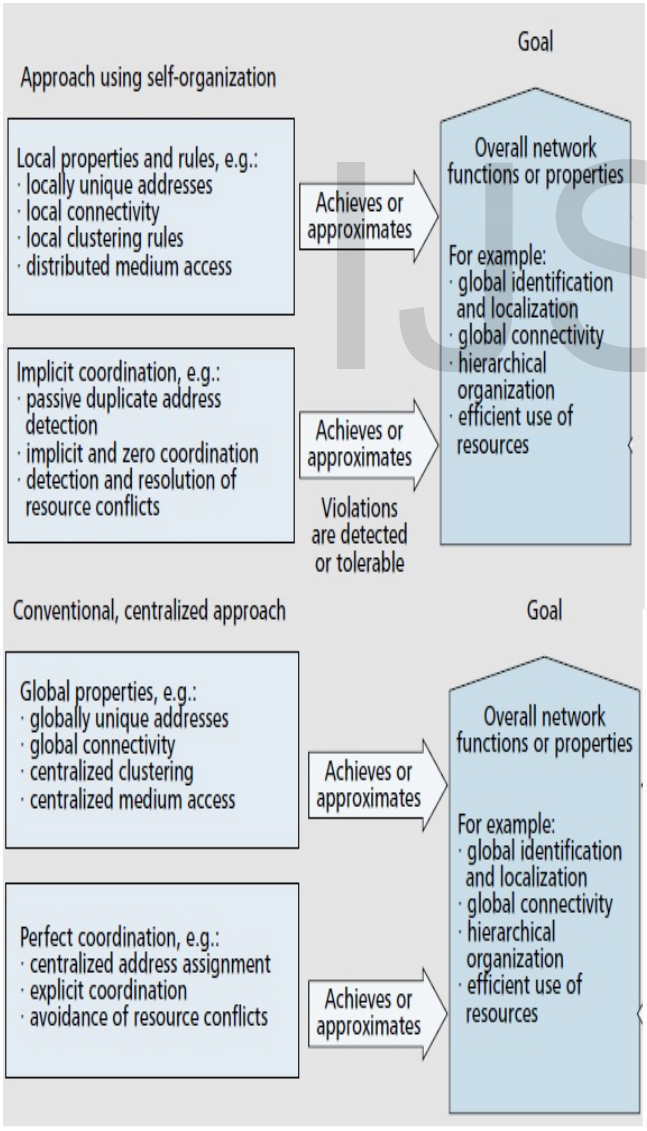

Fig. 2. Self-organization Vs Conventional Networking

In self-organization systems, it uses different approximate optimization algorithms to find optimal path. Find a good enough path within reasonable time rather than strive for convergence on global optimum. Benefits of Self-Organization include Plug-and-Play Technology which is Automation technology intended to make planning, configuration, optimization and deployment of networks easier and faster. New nodes which enter the network are automatically configured without needing human intervention.

3 PROPERTIES OF SELF ORGANIZING NETWORKS

Self-organized networks have very distinct properties. The properties include the following

- **Self-Configuration**

Set system parameters initially without external intervention

- **Self-Management**

Maintain current system configuration in terms of current system parameters

- **Self-Adaptability**

Systems' ability to adapt to changing environmental conditions

- **Self-Protection**

Ability of the system to protect itself from external malicious influences

- **Self-Healing**

Changing system configurations to operate in the presence of failures or to recover from failures

- **Self-Optimize**

Ability of the system to configure local components optimally based on global objectives

- **Self-Diagnosis**

Ability of a system to detect faults and initiate self-healing

Self organization system basically strives on the basis of different kinds of feedbacks that come in by interacting with the system. These feedbacks can be positive feedbacks or negative feedbacks. When we concern specifically on routing, the feedback is used for erroneous path discovery. When we concern specifically on clustering, the feedback is used to find remaining energy of a node to elect the cluster head. When we concern specifically on directed diffusion, the feedback is used to find interest messages. When we concern specifically on co-ordination, the feedback loops used for synchronization.

Similarly for collaboration, the positive feedback is used in auction based task allocation.

4 DESIGN PARADIGMS IN SELF-ORGANIZING NETWORKS

Paradigm #1: Design local behavior rules that achieve global properties

To design a network function that establishes a global property, this paradigm is to distribute the responsibility among the individual entities. No single entity is "in charge" of the overall organization, but each contributes to a collective behavior. Following this paradigm localized behavior rules must be devised, if applied in all entities, automatically lead to the desired global property (or at least approximate it).

Paradigm #2: Do not aim for perfect coordination: exploit implicit coordination

Implicit coordination means that coordination information is not communicated explicitly by signaling messages, but is inferred from the local environment. A node observes other nodes in its neighborhood and based on these observations, it draws conclusions about the status of the network and reacts accordingly.

Paradigm #3: Minimize long-lived state information

To achieve a higher level of self-organization, the amount of long-lived state information should be minimized. In general, the more localized the interactions are and the less coordination is needed, the less state information must be maintained.

Paradigm #4: Design protocols that adapt to changes

The need for the capability of nodes to react to changes in the network and its environment typically arises from changed resource constraints, changed user requirements, node mobility, or node failures. Since there are no centralized entities that could notify the nodes about changes, each node has to continuously monitor its local environment and react in an appropriate manner. Three levels of adaptation can be distinguished.

- **Level 1:** A protocol is designed so that it can cope with changes, such as failure and mobility.
- **Level 2:** A protocol is designed to adapt its own parameters (e.g., value of timers, cluster size) as a reaction to changes in order to optimize system performance.
- **Level 3:** A protocol is designed so that it realizes if the changes are so severe that the currently employed mechanism is no longer suitable. To detect such situations the environment is observed, and significant changes in major parameters trigger a fallback or alternative solution.

5 SELF-ORGANIZATION MECHANISMS IN MANETs

- **Self-configuring and self-organizing**

Two very important mechanisms for self organization behavior are known as self-configuring and self-organizing. These two mechanisms are based on typical approaches known as route discovery approach and route update approach. Route discovery which can be done proactively or on-demand. Routs are discovered between pairs of nodes. In route update, single or multiple routes are maintained between a pair of nodes and update the current topology by detecting the node or link failures. Route discovery and route update are two important routing mechanisms that are good examples for self-configuring and self-organizing behavior of MANET.

- **Self-optimizing**

Self-optimizing which helps to improve the routes with respect to route length (path aware) or energy consumption (energy aware).

- **Self-healing**

Self-healing is a very important mechanism for ensuring fault-tolerance in MANETs. There are two types of fault-tolerance

a. Masking fault-tolerance
b. Non-masking fault-tolerance

Masking fault-tolerance guarantees that the system continues to keep its functionality in the presence of faults. Whereas non-masking fault-tolerance guarantees that when faults stop occurring, the system converges to configurations from where it continues to function.

Adaptive systems and self-healing systems are quite closely related. Adaptive means that whenever some kind of abnormalities arises, the system will be able to adapt to it so that it functions the way it is supposed to function. Self-healing also supposed to heal on their own whenever there is a problem or failure.

6 EXAMPLES: LEACH

Self organization in MANETs has certain issues like ad hoc deployment, error-prone wireless medium, limited resources and energy constraint. First proposed self-configuring protocols basically periodically discard the network topology information and rebuild it from scratch. One of the very popular self organization protocols that is used in MANET is a cluster-based routing protocol which is known as LEACH. The protocol LEACH abbreviated as Low Energy Adaptive Clustering Hierarchy proposed by Handy, Haase, Timmermann in 2002

- Application of LEACH
  - Ensure even distribution of power consumption of individual nodes in sensor networks.

- Assumptions
  - Each node can act as a regular node or as a cluster head
  - Regular nodes only communicate with their cluster head
  - cluster heads supports data aggregation and data forwarding to neighboring cluster heads or base stations
- Principles
  - Nodes elect themselves to become cluster heads at any given time with a certain probability (based on remaining energy)
  - The cluster heads broadcast their status to the other nodes in the network
  - Each node determines to which cluster it wants to belong by choosing the closest cluster head (e.g. which requires the minimum communication energy)

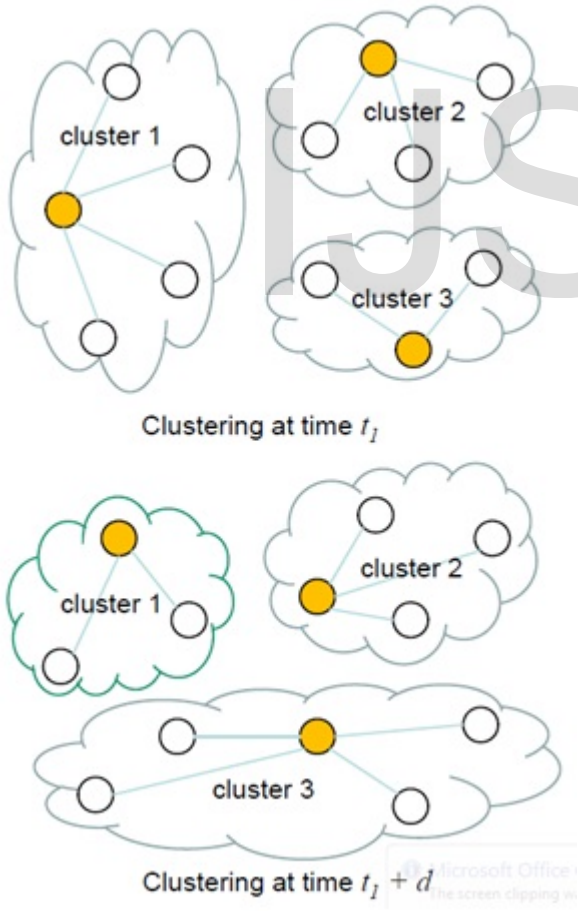

Fig. 3. Cluster-based routing protocol LEACH

7 STATES OF SELF-ORGANIZED SYSTEM

A typical self-organized system would go throw three different states i.e. Normal state, degraded state and broken state. In the normal conditions, the system would be in the normal state and when there is some kind of failure then it goes to the degrades state. After recovery, the system comes back to normal state or if there is a detection of system failure then it goes to the broken state. From the broken state, through the recovery processes the system can bring brought to the normal state. The following figure shows the different states of self-organized system.

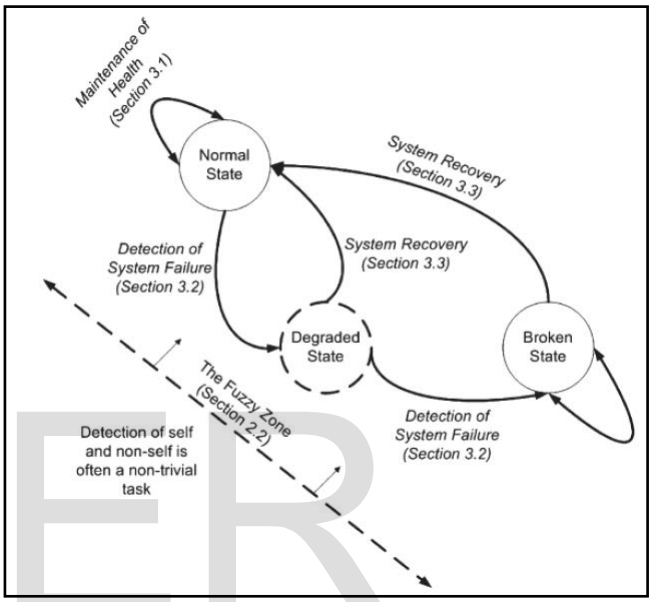

Fig. 4. states of self-organization system

8 LIMITATIONS OF SELF-ORGANIZATION

There are different limitations for self-organization in MANETs. It's not like so far what we present is all the very glittering aspects of self organization networks. It's not that the self organization networks are bold and glitters a lot.

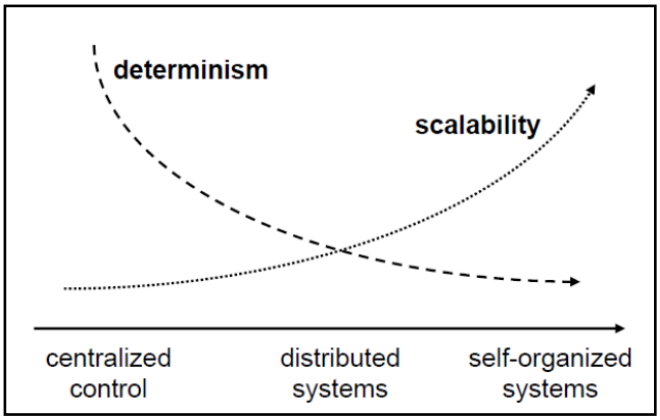

Fig. 5. Comparison of multiple systems

Form the above figure, the two curves shows trade-off between determinism and scalability with respect to systems which are highly centralized, distributed systems and self-organized systems. As we can see, when the systems become more and more self-organized, the deterministic behavior it reduces. The deterministic behavior reduces from centralized systems to distributed systems to self-organized systems, whereas the trend is completely opposite with respect to scalability. Self-organized systems are much more scalable when compare to distributed and centralized systems. Further, new software engineering approaches are needed for self-organization.

9 CONCLUSION

In conclusion, it can be said that self-organization mechanisms create many new and exciting application areas for ad hoc communications. This paper contributes to the networking community by providing a broad introduction and classification to the concepts and ideas of self-organization. After outlining the basis methods of self-organization, we presented a general definition and classification of self-organization mechanisms in ad hoc and sensor networks. Additionally, we discussed the need for such techniques for operation and control in massively distributed systems. Based on the categorization and some clarifying case studies, we have shown that there are already a number of self-organization techniques used for communication and coordination in ad hoc and sensor networks.

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