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A Survey on Graph Based Service Discovery Approaches for Ad hoc Networks

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Abstract: The concept of service is frequently used as an abstraction of software and hardware resources. Service oriented architectures should offer mechanisms of service discovery, advertisement and location. So, it represents a key problem in very dynamic networks like ad hoc networks. Various research treating the communication in these networks carried an unquestionable interest to use virtual dynamic topologies to get a better network organization. In this paper, we give a classification and discuss the different virtual topologies in ad hoc networks and their advantages in implementing service oriented applications.
Keywords: Service discovery, ad hoc networks, graphs.

1. Introduction

A challenging research area in computer networks is ad hoc networks (or MANETs: Multihop Ad hoc NETworks). These are defined to be spontaneous and totally autonomous networks. The communication can be achieved only between a node and its direct neighbors via wireless channel(s). To perform communication at a larger scale, nodes must cooperate to form a multihop route between a source and its destination. Nodes can move randomly and so, network connectivity may frequently change.

Many communication protocols like routing, resources sharing, service discovery or location, prediction, etc use flooding mechanism to diffuse or gather information. Because of this, recent works try to optimize data flows and exchanges. Several studies proposed to construct and maintain virtual dynamic topologies over the ad hoc network. This is done, more generally, to get a better network organization. The presence of such structure ought to:

- decrease the mobility impact. Indeed, if an intermediate layer (the virtual topology) can offer mechanisms treating mobility issues, this may make the design of applications easier (in term of mobility considerations).
- optimize broadcasts. Electing only some nodes and/or links to forward messages decreases considerably message overhead.
- improve scalability, which is a direct consequence of the two statements above. A good network organization simplifies the design in term of scale considerations.
- reduce response times.
- take into account load balancing mechanisms in the configuration induced by the virtual topology.

An abstract view of services is adopted by most of network protocols designers. This abstraction uses the following terminology:

- Service: every software or hardware feature which can be used locally or remotely.
- Server: device offering at least one service.
- Client: device asking for one or more services.
- Peer: server and/or client entity.

Most of service oriented protocols rely on client/server paradigm with peer to peer extension (one node can be, at a given time, either client or server). In our study, we do not consider neither service descriptions/definitions nor the matching/mapping between requests and descriptions.

In this paper, we discuss and comment the different dynamic virtual topologies in ad hoc networks and their advantages in implementing service oriented applications in terms of discovery, advertisement and location. The paper is organized as follows: The following section discusses the related works and situates our work in the context. Section 3 proposes a classification of graph based protocols in ad hoc networks. Each one of its subsections describes and discusses a class of virtual topologies. The last section concludes the paper.

2. Related Work

As mentioned in the introduction, most of service oriented protocols rely on the traditional client/server paradigm including the peer to peer version. However, a new classification of service interaction paradigms has been proposed recently [7] (see Figure 1).

According to Gaber's classification, there are three main interaction paradigms:

1) The traditional Client to Server Paradigm (CSP): in this paradigm, the client should initiate a request for a service or a resource, should foreknow its existence, and should be able to provide its location. This paradigm includes the peer to peer version and the push and pulls extensions. Clients can send their requests reactively, and so, each server receiving this message, if it satisfies the request, replies to the client (Pull model). Also, clients can stand listening passively at service announcements generated proactively by servers (Push model). In both models, a distributed/decentralized approach is adopted.

Salutation [10] and UPnP [10] protocols use this approach. An alternate scheme involves a central server to be responsible of indexing all network services. Jini [10] and SLP [10]

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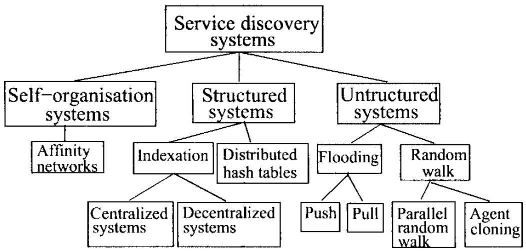

Fig. 1. Classification of service discovery approaches.

protocols specify presence of such server. This being, network dynamicity (main characteristic of peer-to-peer environments) is an important concern in protocol design. Two main solutions were held to resolve the problem. The first introduces the leasing mechanism in which servers define a service life time. The second is based on notification mechanisms. Clients are informed of services availability, departure, state change, etc. Theses two solutions can be combined.

2) The Adaptive Services to Client paradigm (SCP): unlike the classical Client/Server approach (in fact a reverse one), it is the service that comes to the client via a self-adaptive and reactive intelligent network (or middleware). An approach inspired by the human immune system uses both random walks and a cloning mobile agent-based technique for resource discovery in large scale networks with a reinforcement learning mechanism to construct dynamic communities of servers (i.e. dynamic service graphs connecting servers that can join or leave the network in unpredictable manner) that provide a similar or could provide composed services [1]. This paradigm suits to ubiquitous computing where the classical approaches and protocols cannot directly be applied. Moreover, energy and bandwidth constraints do not allow excessive message exchanges.

In this scope, many service discovery protocols were proposed. Allia [20] is a peer-to-peer caching based and policy-driven agent-service discovery framework to facilitate cross-platform service discovery in ad-hoc environments for mobile electronic commerce applications. This approach tries to remove the problems associated with structured compound formation of agent communities in mobile commerce environment and achieves high degree of flexibility in adapting itself to the changes of the ad-hoc environment. GSD [3], Group-based Service Discovery for Manets is based on the concept of peer-to-peer caching of service advertisements and group-based forwarding of service requests. It does not require a service registry or lookup server.

Services are described using an ontology based on the DARPA Agent Markup Language. It exploits the semantic class/subclass hierarchy of DAML to describe service groups and uses this semantic information to selectively forward service requests to respective nodes. Konark [13] is a service discovery and delivery protocol designed specifically for ad hoc, peer-to-peer networks, and targeted toward device-independent services in general and m-commerce oriented software services in particular. It has two major aspects-service discovery and service delivery.

For discovery, Konark uses a novel decentralized, peer-to-peer mechanism that provides each device the ability to advertise and discover services. The approach toward service description is XML-based. It includes a description template that allows services to be described in a human and software understandable forms. A micro-HTTP server present on each device handles service delivery, which is based on SOAP. In Lenders et al. protocol [16], authors achieve distributing information about available services in the network by using the analogy of an electrostatic field: A service is modelled by a (positive) point charge, and service request packets are seen as (negative) test charges which are attracted by the service instances. In their approach, they map the physical model to a mobile ad hoc network in a way where each network element calculates a potential value and transmits service requests to the neighbor with the highest potential.

3) The Spontaneous service emergence Paradigm (SEP): dynamic affinity networks are created on the fly between nodes of an ad hoc network [8]. Affinity corresponds to the adequacy with which two services could bind to create a composed service or to point out a similar service. This paradigm suits to pervasive computing.

Thus, CSP involves graphs wherein some nodes are repositories or registries, SCP involves dynamic communities between servers constructed by random walks and/or mobile agents, SEP involves emergent affinity graphs. In spite of this, the first category (based on flooding optimization) is widely adopted in ad hoc networks because of its design simplicity, performance and, foremost, for its real network topology considerations (which improve network behavior: mobility impact, broadcast overhead, response times, etc).

In the following, we give a classification of mostly used topology based (graph based) solutions in ad hoc networks.

3. Classification of graph based works

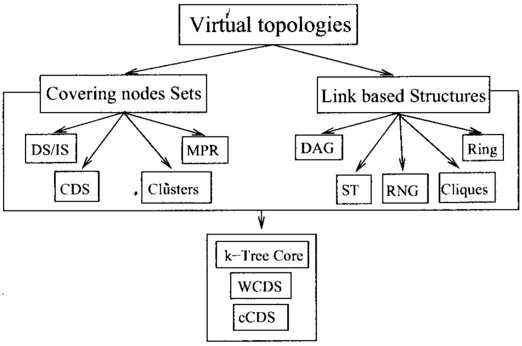

Fig. 2. Virtual topologies classification.

Let $G = (V, E)$ be the graph modelling the network such that V is the set of vertices (representing nodes) and E is the set of edges (representing links). Let u and v be two vertices of G. The distance between u and v is the length of the shortest path having u and v as extremities. We denote by $dist(u, v)$ the distance between the two vertices u and v. The set of neighbors of the vertex u is denoted $N(u)$. We define the k-neighborhood (also, k-hop neighborhood) of the vertex u to be the set of all vertices which are at most at distance k from u.

In our review of existing virtual topologies, we were brought to classify them into two main classes (see Figure 2):

- *Covering node Sets:* This class is based on subsets of V which share some properties (like covering property, dominating property, ...). It regroups Multipoint relays (MPR sets), Dominating Sets (DS), Independent Sets (IS), etc
- *Link Based Structures:* This class is based on subgraphs of G, generally, $G' = (V, E')$ where E' is a subset of E. It regroups Neighborhood Graphs (NG), Spanning Trees (ST), Rings, etc

Also, recent works introduced some new definitions which aim to "mix" the advantages of both classes; we regroup these topologies in a third class called *"mixed" structures*. In the following, we discuss each class.

3.1 Covering node sets

Virtual topologies of this class, usually, choose a subset of nodes which will be considered as network backbone. In other words, the chosen nodes will have some privileges and responsibilities according to the problem. In the case of service oriented applications, these nodes should ensure the tasks associated to services, like:

- Hosting services and their descriptions.
- Forwarding requests.
- Applying policies of load balancing.
- ...

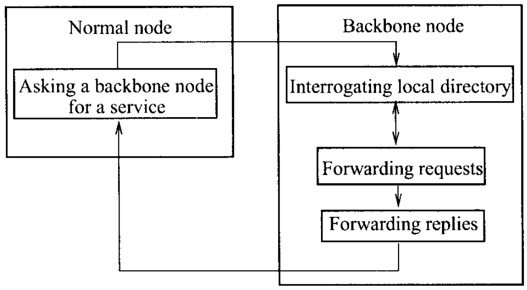

Fig. 3. Application general scheme.

Not backbone nodes (normal nodes) interrogate privileged nodes to get/access a given service. Backbone nodes should, then, cooperate to satisfy the request. They also can construct between them a distributed directory containing all information concerning network services. The most known topologies which are based on covering nodes are:

3.1.1 Multipoint relays

The set of multipoint relays (MPR) of a node is a minimal size subset of its 1-hop neighbors that "cover" all its 2-hops neighbors. This technique restricts the number of retransmitters to a subset of neighbors instead of all of them (like in pure flooding). Each node selects, using its local information, a subset of its neighborhood which retransmits its packets. Figure 4 shows

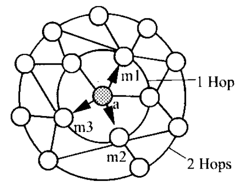

Fig. 4. Multipoint relay set example.

an example of an MPR set for the node a. When a wants to broadcast a message, only m_1, m_2 and m_3 forward it. In [17], authors propose the QOLSR protocol which includes quality of service (QoS) parameters to the standard OLSR. Three variants of QOLSR are introduced. Some new heuristics for the multipoint relay selection are also proposed.

3.1.2 Dominating and Independent sets

A Dominating Set (DS) of the graph G is a subset S of V such that every vertex of V is either in S or adjacent to at least one vertex of S (i.e. for each $v \in (V \backslash S) : N(v) \cap S \neq \emptyset$). A Minimal Dominating Set (MDS) is a dominating set such that no subset of it, satisfies the dominating property. (see Figure 5). An Independent Set (IS) in the graph G is a subset S of V

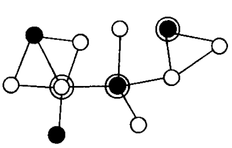

Fig. 5. Dominating set (surrounded) / Maximal independent Set (black).

such that S does not admit any pair of adjacent vertices (i.e. for each $v \in S : N(v) \cap S = \emptyset$). The independent set S is said Maximal Independent Set (MIS) if there is no independent set S' such that $S \subset S'$. For any maximal independent set, we have the following properties:

- Any pair of complementary subsets of a MIS are separated by either two or three hops.
- A MIS is also a DS.

[14] proposes a service discovery protocol for ad hoc networks. This last uses the concept of dominating set in its architecture. A directory agent is associated to every dominating node.

3.1.3 Clusters and k-clusters

A cluster is a subset of nodes of the underlying network that satisfies or share a certain property. The precise definition of this property varies within different contexts. Most node-centric clustering schemes insist on the existence of a central node adjacent to all the remaining nodes in the cluster. This central node is referred to be cluster-head. In this case, the corresponding property is known as the dominance property. In the presence of a central node, consensus is reached trivially: it is decided by the central node. However, cluster-heads should cooperate between them to perform larger scale operations (for example, locating a service ...). The k-Clustering technique

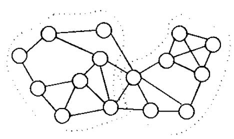

Fig. 6. A 4-clustering of the graph.

consists in partitioning the network in a minimal number of clusters whose respective diameters do not exceed k hops (see Figure 6).

[15] provides QoS-sensitive routes in a scalable and flexible way in network environment with mobility. In the proposed scheme, each local node needs only to maintain local multicast routing information and/or summary information of other clusters (or domains) but does not require any global ad hoc network states to be maintained.

3.1.4 Connected dominating sets

A Connected Dominating Set (CDS, see Figure 7) of the graph G is a subset S of V such that:

- Vertices of S form a dominating set of G.
- The induced subgraph by the set S is connected.

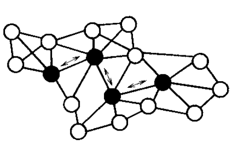

Fig. 7. A connected dominating set.

Constructing a connected dominating set generally aims to get a better topology control strategy by reducing the network communication overhead. In [22], an energy efficient distributed connected dominating set algorithm based on coordinated reconstruction mechanism is presented. Authors try to prolong the network lifetime and balance energy consumption.

Some variants of CDS were also introduced by extending concept of traditional (1 hop) domination to d-hops domination or by seeking some fault tolerance properties (k-connection).

A d-Dominating Set (d-DS) of the graph G is a subset S of V such that each vertex of V is either in the d-DS S or in the d-neighborhood of at least one vertex of S. Let $G = (V, E)$ be a connected graph, the d-closure of G is the graph $G_d = (V, E_d)$ such that $E_d = E \cup D$, where D is the set of all "virtual" edges connecting each node with all others in its d-neighborhood. For a graph G and its d-closure G_d, we have:

- A set S is a d-DS in G, if it is a DS in G_d.
- A set S is d-hop connected in G, if is connected in G_d. If also S is a d-DS then we say that S is a d-CDS.

The notion of d-CDS is also used to induce a clustering of the graph G. [21] proposes the Three-hop Horizon Pruning (THP) algorithm to compute two-hop connected dominating set (TCDS) using only local topology information.

A graph $G = (V, E)$ is k-vertex connected if it is connected, and removing any $1, 2 \ldots k-1$ vertices from G will not cause partition in G. The concept of k-connectivity is usually used in the context of fault tolerance support. A subset S of V is a k-Dominating Set [5] (k-DS) of G if every vertex not in S has at least k neighbors in S. A k-DS is a k-Connected k-Dominating Set (k-CDS) if the subgraph induced by the k-DS is k-vertex connected.

3.2 Link based structures

This class is based on subgraphs of the network graph. Contrary to the first one, this class is based on minimizing number of used edges (links). This aims to minimize the communication overhead. Indeed, the different service requests can induce a broadcast storm in the network. So, by diminishing the

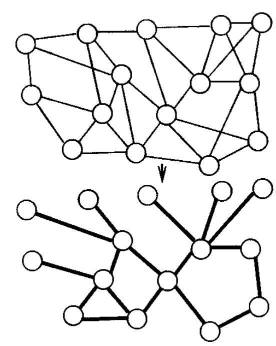

Fig. 8. Diminishing the number of edges.

number of edges without losing network connectivity, the congestions due to redundant message may decrease. The most known link based topologies are:

3.2.1 Neighborhood graphs

Given the graph G, neighborhood graphs construct a subgraph of G which keeps its connectivity but try to minimize the graph degree (essentially by eliminating transitive edges). Here, we give two examples of these graphs. Relative Neighborhood Graphs and Gabriel Graphs. A Relative Neighborhood Graph (RNG) contains an edge uv if the intersection of the two disks respectively centered at u and v with radius equals to dist(u,v), is empty of other vertices. A Gabriel Graph (GG) contains an edge uv if the disk with uv as diameter is empty of other vertices (see Figure 9).

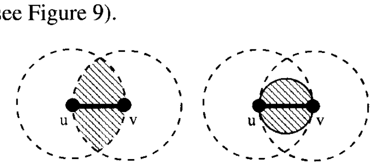

Fig. 9. RNG and GG.

[2] considers both topology control and broadcast oriented protocols. It describes localized protocols where nodes require only local information about their neighborhood (distances or geographic positions). The proposed solutions are based on the use of neighbor elimination scheme applied on the relative neighborhood graph (RNG) and local minimum spanning tree (LMST).

3.2.2 Spanning trees

A tree is an undirected graph $T = (V, E)$ which is connected and has no cycle. If V is finite and $|V| = n$ then $|E| = n - 1$. Let $G = (V, E)$ be a connected graph. A spanning tree of G is any subgraph $T = (V, E')$ which is a tree. The following figure shows a spanning tree example. Spanning trees [18]

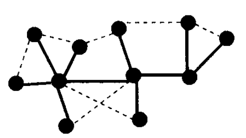

Fig. 10. A spanning tree.

are very useful in broadcasting and multicasting applications. Indeed, the tree structure of the topology guarantees the broadcast reachability of all vertices with a minimum number of messages.

3.2.3 Rings

A network is a ring topology if every node has exactly two branches connected to it (If the ring is oriented then these branches indicates the predecessor and the successor). There is only one cycle between a node and itself. Further, this cycle contains all nodes in the network.

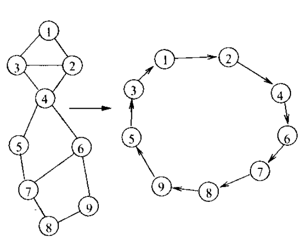

Fig. 11. Virtual Ring Construction.

Contrary to other topologies, which are based on physical network connectivity, this topology is more "virtual". Indeed, in general, the construction of this kind of topologies relies on the routing layer (see Figure 11). Rings are in general used to distribute "circularly" a privilege. Many token and agent oriented solutions use virtual rings.

[4] proposes a self-stabilizing mutual exclusion algorithm for mobile ad hoc networks, in which the composition of processors that want to enter the critical section can change dynamically. The proposed algorithm is based on dynamic virtual rings formed by circulating tokens. The algorithm guarantees different levels of progress under different levels of performance of the token circulation in the presence of mobility and message loss.

3.2.4 Cliques

Let $G = (V, E)$ be a graph. If a subgraph G' of G is a complete graph (i.e. there is an edge between any two vertices of G') then G' is called a Clique. A maximal clique of G is one that is not contained in any other clique (see Figure 12). Cliques

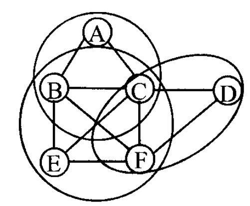

Fig. 12. Maximal Cliques ABC, BCEF, CDF.

are essentially used in QoS applications. [11] use a conflict graph that models the interference relationship between links to determine if a set of flow rates can be accommodated. Using the cliques of the conflict graph, authors derive constraints that are sufficient for a set of flow rates to be feasible and guaranteed to be within a constant bound of the optimal. They also extend the ad hoc network model to incorporate variations in the interference range, and obstructions in the network.

3.2.5 Directed acyclic graphs

In this kind of topologies, we consider a directed graph $G = (V, A)$ where A is a set of arcs (*"directed" edges*). If G does not have any directed cycle, then G is a Directed Acyclic Graph (DAG, see Figure 13). These topologies are much used in Link

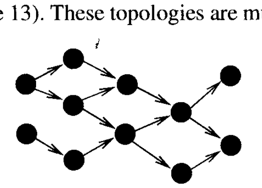

Fig. 13. A Directed Acyclic Graph.

Reversal (LR) approaches. An example is the Link Reversal Routing (LRR). LRR algorithms construct a DAG "Rooted" at the destination. This involves that there is no loop between a source and its destination. Also, only the destination may have not outgoing links.

[19] treat On-demand routing protocols which flood a route request identified by a unique source-sequenced label to build directed acyclic graphs consisting of possible paths to destinations, and use reverse paths along such DAGs to send route replies from the destinations.

3.3 Mixed Structures

A skilful virtual topology is the one which combines the advantages of the two previous classes. In other words, a mixed topology chooses a best set of nodes which dominates the remaining nodes with a minimum number of links. Indeed, a good virtual topology should offer: well connectivity (for fault tolerance purposes, especially in link based class), small diameter (to minimize virtual distance between each pair of nodes), a good regularity (to homogenize treatment procedures), weak energy consumption, and a fair behavior towards wireless medium access. In addition to these characteristics, it is necessary to construct and maintain the topology in reasonable message and time complexity. However, a well virtual topology can respect most of the criteria mentioned above.

3.3.1 k-tree core

Given a tree T, a "k-Tree core" of T is defined as the subtree T' with exactly k leaves and which minimizes the distances sum to all other nodes in T. If $k = 2$, then T' is simply a "core" of T (T' is a path in this case) (see Figure 14)

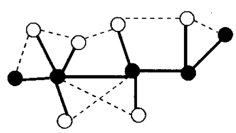

Fig. 14. A core of the tree.

This topology offers a non trivial d-dominance property for the induced backbone by the k-tree core. [9] proposes to construct a clustering of the network based on a k-tree core backbone. It distributes the routing load on the cluster gateways without adding the extra overhead of maintaining information about dense cluster gateways.

3.3.2 Weakly connected dominating sets

A Weakly Connected Dominating Set (WCDS, see Figure 15) of the graph G is a subset S of V such that:

- Vertices of S form a dominating set of G.
- By connecting every two vertices of S that are at distance 1 or 2, the induced subgraph is connected.

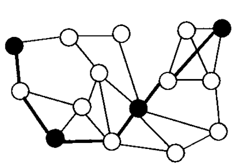

Fig. 15. A weakly connected dominating set.

[6] gives an interesting distributed construction of WCDS in ad hoc networks.

3.3.3 Cliques connected dominating sets

In [12], authors proposed a service discovery protocol based on a new construction of connected dominating set (virtual backbone). This construction is based on concepts of maximal independent sets and cliques. It is performed as follows:

a) Choose a subset which forms a MIS.

b) Form the 3-closure (to add virtual links between any pair of remote nodes within two or three hops one from the other) of the graph modelling the network (but we do this only for the induced subgraph by the MIS nodes).

c) Regroup MIS nodes into cliques in the 3-closure.

d) Find a minimal core of connectors for each clique in the 3-closure.

e) The union of the MIS nodes and the connectors thus selected forms the CDS.

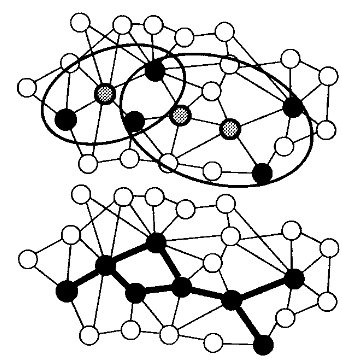

Fig. 16. A clique connected dominating set.

CDS vertices will have the responsibility of registering and locating services. Each node of the network will have at least a node of the CDS in its neighborhood. The nodes of the CDS form, between them, a peer to peer network. They maintain local caches which are useful, mainly, to record information concerning the services.

4. Conclusion

Wide research areas in ad hoc networks gave much interest to use dynamic topologies to improve general network behavior. In this paper we propose a classification of popular virtual dynamic topologies in ad hoc networks. Also, we describe these techniques and their usefulness in communication protocols (Routing, Resource sharing, Service discovery, etc) which may induce skillful considerations in any service oriented application design.

The main aim of covering sets techniques is to determine a subset of all nodes in the network that can be used as a virtual backbone (which allows implementing various applications on this backbone). Dominating sets and maximal independent sets structures are generally used as sets of privileged nodes that have to perform a special role (like distributed directory agents, etc).

Clusters give a hierarchy in the network, nodes are regrouped into families which may have or not a cluster head. Connected dominating sets based approaches use a connected structure to diffuse or gather information.

On the other hand, Link Based techniques try to give a certain orientation to data flows by reducing number of used links in larger scale communication. A directed acyclic graphs based approach "direct" the network from a source to a destination. This gives a multipath routing property. Neighborhood graphs based techniques try to reduce communication flows overhead to a minimal value but may have some fault tolerance issues.

In the same context, tree goes further by eliminating all communication cycles. Cliques are generally used to determine some bounds on network capacities (bandwidth, congestion points, etc). Rings give some privilege sequence. Nodes access the privilege each one on its turn.

One can think about creating a mixed topology, *"link based on covering nodes"*. This may exploit advantages of both classes. In fact, reducing used links between covering nodes can produce more powerful backbone. A k-tree core can be used as a virtual backbone for data/service dissemination in the network, since each node is not so far from the k-tree core. The WCDS decreases the constraint of the direct connection of backbone nodes. This aims to diminish the number of backbone nodes. Also, the clique connected dominating set combines between maximal independent sets and cliques concepts to diminish number of backbone nodes. This backbone was designed in order to get a better service discovery performance in such environment.

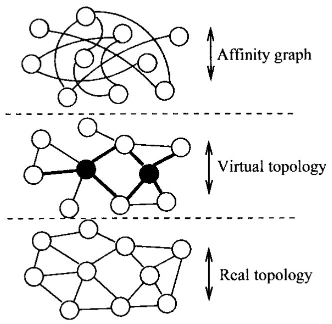

Fig. 17. Correlation between graph models and semantic models.

However, if we consider the classification proposed in Figure 1, most of proposed graph based approaches deal with unstructured systems (more precisely, with flooding optimization techniques). Since the structured systems impose a rigid network organization, dynamic virtual topologies may not have a direct application except the rigidity of network structure is softened to admit a specified level of virtualization. Conversely, in the self-organization systems, especially in affinity networks approaches, a challenging problem is to find an adapted dynamic virtual topology which can maintain as stable as possible the affinity network graph while the real topology of the ad hoc network is changing (see Figure 17).

Indeed, in general, nodes are randomly distributed in the ad hoc network. So, nodes sharing the same interests (have some affinity) are not always geographically collocated. This makes the distances between nodes in affinity graph much different from distances induced from real topology graph. So, if we bring an intermediate layer virtual topology which tries to insure the communication between nodes according to the affinity graph, the general performance of affinity graph based protocols may considerably increase.

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