

Localized Communication and Topology Protocols for Ad Hoc Networks: *A Preface to the Special Section*

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1 THE SCOPE

WE are very proud and honored to have been entrusted to guest edit this special section. The main goal was to put together a strong issue emphasizing quality and relevance to current interests in this important field. Papers were sought to cover comprehensively the algorithmic issues in the “hot” area of ad hoc and sensor networking. The concentration was on the network layer problems which can be divided into two groups: *data communication* and *topology control* problems. In data communication problems, such as routing, quality-of-service routing, geocasting, multicasting, and broadcasting, the primary goal is to fulfill a given communication task successfully between nodes in an ad hoc network. The secondary task is to minimize the communication overhead and power consumption given that in the vast majority of applications nodes run on batteries. Topology control problems are further subdivided into neighbor discovery and network organization problems. In the neighbor discovery problem, the problem is to detect neighboring nodes located within transmission range. In the network organization problem, each node should decide what communication links to establish with neighboring nodes (an example is the Bluetooth scatternet formation problem), and what power management schemes to adopt (examples are “sleep” period operations and adjusting transmission ranges).

Due to their theoretical challenges and myriads of practical applications, wireless sensor networks are emerging as one of the priority research and development areas. The applications of sensor networks are envisioned primarily for monitoring the environment (e.g., motion detection, chemicals, temperature) or as key components in embedded systems (e.g., biomedical sensor engineering). This special section also sought submissions on this “hot” topic, including problems such as: physical properties, sensor training, security through intelligent node cooperation, medium access, sensor area coverage with random and deterministic placement, object location, sensor position

determination, energy efficient broadcasting and activity scheduling, routing, connectivity, data dissemination and gathering, sensor centric quality of routing, path exposure, tree reconfiguration, topology construction, and transport layer.

The main paradigm shift is to apply localized schemes as opposed to existing protocols requiring global information. Localized algorithms are distributed algorithms where simple local node behavior achieves a desired global objective. Localized protocols provide scalable solutions, that is, solutions for wireless networks with an arbitrary number of nodes, which is the main goal of this plan. Sensor and rooftop/mesh networks, for instance, have hundreds or thousands of nodes.

2 PROPERTIES OF LOCALIZED ALGORITHMS

The community does not have a unique understanding of what a localized algorithm is. We would like to provide here some further explanations, examples, and some further relevant criteria for the design of such protocols. Localized protocols offer the best prospect for achieving energy efficiency. In a localized protocol, each node makes protocol decisions based solely on some local knowledge available (to be more precise, based on the information from neighbors within k hops for certain small k , such as $k = 1$ or $k = 2$), without resorting to global network information. Some (called beaconless) protocols even do not need the knowledge of neighbors. For example, a node currently holding a packet may send a request to all its neighbors asking to forward it toward the destination and a neighbor closest to the destination may respond first.

Because of the dynamic nature of ad hoc networks, topology changes are frequent and unpredictable. The local information must suffice for a sensor node to make protocol decisions; otherwise, the increased communication overhead could offset the energy savings and increase latency. In a *centralized* (or *globalized*) algorithm, one or more nodes (or a central entity like a base station) need to learn global node and/or edge structure, either the whole graph (for instance, to find route using the shortest path algorithm), or a global structure derived from the graph (such as minimal spanning tree). Because of huge communication overhead involved in gathering such information in dynamically changing ad hoc and/or sensor networks, such protocols

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cannot be energy efficient solutions in such networks with large number of nodes.

We further classify localized protocols according to the amount of information required and to overhead in the construction and maintenance phases. The amount of required information is related to the *message complexity*, which can be defined as the average number of transmitted messages per node in a protocol. Although some protocols appear to be localized, extensive message exchanges among neighbors amount to collection and use of global information. In a *strictly localized protocol*, all information processed by a node is either local in nature or global in nature, but obtainable in short constant time by querying only the node's neighbors or itself. In other words, only a small constant number of message exchanges with one's neighbors is allowed. Strictly localized protocols may need some information that is part of their input (such as destination position in a routing protocol), but cannot use structures that are global in nature (e.g., information which of outgoing links belongs to minimum spanning tree). Emergent algorithms are an interesting similar notion. An *emergent* algorithm is any computation that achieves formally or stochastically predictable global effects, by communicating directly with only a bounded number of immediate neighbors and without the use of central control or global visibility.

The definitions given so far still leave room for discussion and misinterpretation. For example, it is possible to construct a minimal spanning tree (MST) by a "localized" protocol which is a straightforward adaptation of a well known centralized algorithm. One node can simply play the role of central processor, issue requests for necessary information, make and distribute decisions. Thus, one needs to consider other criteria in declaring whether a protocol is truly localized, and we had a number of such cases while handling submissions to this special section. For example, one needs to consider both construction and maintenance phases. A change in one part of the network may require message propagation and recomputation of the entire structure, such as that of an MST or a typical cluster organization. While clustering has an elegant construction phase, "chain effects" do occur in the maintenance phase. One can consider also the *time complexity* of a protocol. Depth-first search (DFS) based routing, for example, may have unbounded delay (more precisely, delay proportional to the number of nodes in the network) between two visits to the same node. It also requires nodes to *memorize* some information. But, the network is dynamic, and the node keeping stored information may not be available when DFS search returns to that area. Thus, it is preferable to have a solution that avoids memorization, controls decision delays, minimizes messages between nodes and is able to make instant decisions. While we welcomed submissions with variety of properties with respect to mentioned criteria, the acceptance decisions were significantly impacted by these considerations.

3 SUBMISSIONS STATISTICS

In response to the call for papers, we received 114 submissions from all over the world, leading to a truly international

competition. After an initial screening, 13 submissions were declared "out of scope" of this special section and the remaining 101 were sent to reviewers. The initial plan was to accept the seven best articles from all submissions, for one special section. However, the quality and quantity of submissions was overwhelming, and Pen-Chung Yew, the past Editor-in-Chief of *IEEE Transactions on Parallel and Distributed Systems (TPDS)*, kindly agreed to allow us to select an additional seven articles for a second special section (scheduled for the September 2006 issue), and up to seven more articles for regular issues of this journal.

All manuscripts underwent a very rigorous peer review process. After the first round of reviews, only seven articles did not have any major revisions requested, and they were selected for this section. Thirty-nine more articles were moved to the second round of reviewing, with additional reviewers selected for most of them for fair final selection of up to 14 more articles.

Many individuals contributed to the success of this special section. We take this opportunity to thank all the authors for their submissions. We are also indebted to a small army of referees who have put in the hard work and the long hours to review each paper in a timely and professional way! Transactions Assistant Jennifer Carruth did an amazing job in chasing all of us for doing proper job, and provided enormous and valuable assistance. Last, but not least, we are indebted to Pen-Chung Yew for offering us this opportunity and patiently waiting for its completion.

4 A SNEAK PREVIEW

At this point, we feel it is appropriate to briefly introduce the seven papers appearing in this special section.

In "Localized Protocols for Ad Hoc Clustering and Backbone Formation: A Performance Comparison," Stefano Basagni, Michele Mastrogiovanni, Alessandro Panconesi, and Chiara Petrioli compare the performance of leading localized protocols for ad hoc clustering and backbone formation. They assess the effect of "degree of localization" on protocol duration, energy consumption, message overhead, route length, and backbone size. Their thorough study provides readers with experimental evidence for the importance of criteria discussed in this introduction.

In "Localized Fault-Tolerant Topology Control in Wireless Ad Hoc Networks," Ning Li and Jennifer C. Hou discuss the design of energy efficient and fault tolerant topologies for ad hoc networks. They enforce k -vertex connectivity in the topology construction process by proposing a fully localized algorithm, *Fault-tolerant Local Spanning Subgraph (FLSS)*, which minimizes the maximum transmission power used in the network.

In "Localized Topology Control for Unicast and Broadcast in Wireless Ad Hoc Networks," Wen-Zhan Song, Xiang-Yang Li, Ophir Frieder, and Weizhao Wang propose a novel localized topology control algorithm where each node locally selects communication neighbors and adjusts its transmission power, such that that all nodes together self-form an energy efficient topology simultaneously for both unicast and broadcast communications. The network topology is planar, spanner, low-weight, with bounded degree and bounded interference.

In "Efficient Broadcasting in Ad Hoc Wireless Networks Using Directional Antennas," Fei Dai and Jie Wu propose a novel broadcast protocol called *directional self-pruning* (DSP) for ad hoc wireless networks using directional antennas. Compared with its omni-directional predecessor, DSP uses about the same number of forward nodes to relay the broadcast packets, while the number of *forward directions* that each forward node uses in transmission is significantly reduced.

In "Impact of Sensing Coverage on Greedy Geographic Routing Algorithms," Guoliang Xing, Chenyang Lu, Robert Pless, and Qingfeng Huang study greedy geographic routing in surveillance or object tracking systems that provide sensing coverage over a geographic area. They show that an existing geographic routing algorithm, greedy forwarding (GF), can successfully find short routing paths based on local states in sensing-covered networks. They also discuss path dilation of this and a new routing protocol.

In "Performance of a Beacon Enabled IEEE 802.15.4 Cluster with Downlink and Uplink Traffic," Jelena Mišić, Shairmina Shafi, and Vojislav B. Mišić analyze the performance of an 802.15.4 compliant personal area network operating in the beacon enabled mode with both downlink and uplink traffic. They identify points in the standard which limit the network performance, namely blocking of request packets by PAN coordinator, simultaneous arrival of request packets after the beacon and delaying transmissions to after the following beacon.

In "Load-Balanced Short-Path Routing in Wireless Networks," Jie Gao and Li Zhang study routing algorithms on wireless networks that use only short paths, for minimizing latency, and achieve good load balance, for balancing the energy use. They consider the special case when all the nodes are located in a narrow strip and present algorithms that achieve good performance in terms of both measures simultaneously.



Stephan Olariu received the PhD degree in computer science from McGill University, Montreal, Canada. He was the recipient of a US National Science Foundation Research Initiation Award. Professor Olariu's research interests range from parallel algorithms, to graph theory, to wireless networks and mobile computing, to biology-inspired algorithms and sensor network applications. He has published more than 200 articles in top-flight archival journals. He is the



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David Simplot-Ryl received the PhD degree in computer science in 1997 from the University of Lille, France. He is scientific director of the COM research project of IRCICA, and head of POPS research team of INRIA Futurs research unit. His research interests are in the areas of sensor and mobile ad hoc networks, mobile and distributed computing, and RFID technologies. He is editor and guest editor of several journals, cochair of workshops on ad hoc networks at IEEE ICDCS, and general cochair of the InterSense Conference in 2006.

Ivan Stojmenovic received the PhD degree in mathematics. He established three journals (on multiple-valued logic, ad hoc and sensor networks, and on parallel, emergent, and distributed systems), and is editor and guest editor of several other journals. He edited three recent handbooks with Wiley, on wireless networks (2002), ad hoc networks (2004), and sensor networks (2005). He published more than 200 distinct articles and earned Fast Breaking Paper in Computer Science for October 2003 from ISI, and the Award for Excellence in Research in 2005 from the University of Ottawa.

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