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THESIS

**DISTRIBUTION OF INFORMATION IN AD HOC
NETWORKS**

by

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September 2007

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DISTRIBUTION OF INFORMATION IN AD HOC NETWORKS

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ABSTRACT

Ad-hoc networks are distributed, self-organized networks which do not need a fixed infrastructure. Entities in networks of this sort must collaborate to make network services - such as routing - functional. In these environments, many algorithms from wired networks cannot be naively adapted without congesting the network. The author's work is focused on the study of the information distribution protocol. Indeed, without application, ad-hoc network technologies are useless. Managing services consists of providing a reliable and easy way to develop distributed applications.

This work contributes to this study in two specific ways. First, it provides a mathematical model that deals with the best possible site of information source nodes in a graph of infinite density. Thus, nodes can be laid out where desired. Second, it provides an algorithm which achieves an effective distribution of information among the nodes of the network. This algorithm can then be used to publish the description of a service among the network to make its research easy.

This study's results provide a settlement for the design of a distributed of information in ad-hoc networks. Moreover, the results can be used in other application fields such as QoS multi-path routing.

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I. INTRODUCTION

A. OVERVIEW

The current technology for developing electronic components, particularly microprocessors, has made it possible to develop equipment of increasingly reduced size and weight. This has allowed the introduction of increasingly powerful portable data-processing objects, such as portable computers and Personal Digital Assistants (PDA). Currently, laptops are just as powerful as desktop systems. PDA's have reached or even exceeded the power of the PCs of a few years ago. For example, the 'Pocket PC' PDA's are equipped with a processor with 600 MHz and 128 Mb of RAM or more.

The portable character of these devices encourages us to consider new approaches to data processing. The equipment and information that was formerly attached to a place (for example, a desk) now finds itself attached to an individual. Moreover, network technologies have seen many improvements in recent years, providing portable devices with a reliable communication system.

First, connection to the wired networks was made possible. Users' needed to be able to connect to receive data such as their email. But since the advent of wireless networks, laptops or PDAs can connect to the network anytime and without any constraint.

Second, although laptops and new-generation PDAs are the first devices to benefit from this technology, this type of equipment is not the only one within the framework of

mobile data processing. Indeed, data processing is integrated more and more in broader fields of application, such as automobiles and telephony. In the case of the automobiles, the necessary electronic components already exist, and it is easy to imagine the benefits that are sure to arise from future developments in communications.

1. Wired and Wireless Networks

There are a number of significant differences between wired and wireless communication.

First, the radio spectrum, as well as available capacity for data transfer, is limited by government regulation. While additional cables increase the number of users who can be served by a fixed network, the frequency band occupied by a mobile network cannot be increased. This restriction limits available data flow and necessitates an efficient use of the channel.

Second, the quality of radio communications can vary because of various types of interference and mobile devices. Thus, this situation leads to a higher transmission error rate than on a wired network and highly fluctuating data rates.

Another major difference between these two types of networks is the very dynamic character of a wireless network. The access point of an entity on a wired network is fixed, whereas in the case of a wireless network, the user can connect from various places and can even change access points during connection. Thus, the problem is: first, to find a user in the network and making it possible for that

user to be reached. Second, it is necessary to maintain a transparent connection, in spite of its mobility and its changes of zone of communication.

Yet another important aspect is that physical access to a wireless network's data cannot be protected. In contrast, a wired network's data can be protected at access points and through the cables connecting the various stations. In the case of a wireless network, anyone can listen to the network; he can thus recover data forwarded via an air interface. This requires the use of coding and authentication mechanisms to ensure data confidentiality.

Currently, the principal use of wired networks is within the framework of a centralized architecture. In the case of GSM [1] or WiFi (IEEE 802.11 b/g [2]), users are connected to a central access point which provides them access to the network. Current research proposes solutions without an access point, and based on the collaboration of the entities forming the network. Thus, each object functions as a router, relaying packages to support the communication of other objects which are out of range. This type of network is called an Ad Hoc Network and is supported by a working group of IETF (Internet Engineering Task force) known as MANET (Mobile Ad hoc NETWORK) [3].

2. Ad Hoc Networks

If the deployment of an infrastructure is too expensive, or impossible for reasons including a difficult or hostile environment, the need for rapid deployment, and so forth, a distributed solution may allow users to extend their communications beyond the range of their radio

interface. Each network user can relay messages so that all users can communicate with all others, regardless of the distance separating them, provided there are enough users in the path. The network thus provided is autonomous, and is supported by the collaboration of all participants.

Many challenges arise when attempting to provide the same functionalities of wireless networks through ad hoc networks. The problem which will be examined here is that of information distribution. How can information be distributed? How can the number of nodes that move information over the network be minimized? This thesis attempts to provide answers to these questions by proposing a solution, dedicated to an ad hoc environment.

B. MOTIVATION

Historically, military was the first to use ad-hoc networks. This type of network makes it possible to deploy a means of communication among different groups of units via vehicles which communicate over radio. Ad hoc networks are also very useful in the case of a hostile environment. Moreover, because an ad hoc network is auto-organized and does not require infrastructure, it can be deployed quickly and simply. Due to the mobility of the network many problems may occur during its use. Thus, more sources of information are required to keep it working properly. For that, the network requires a perfect distribution of information, which allows all members of the network to get information anytime and from any place. The distribution of information in ad hoc networks is an interesting issue, although it is still ambiguous and is considered one of their weak areas. It is the goal of this thesis to outline the best

distribution of information in ad hoc networks, as regards to minimizing the number of nodes needed to cover the entire zone being served.

C. PROBLEM STATEMENT

Whatever the type of information required, its use will necessarily pass a key point. Indeed, at a minimum, one must discover which network device provides information before one can use it. In the wired world, the solution is simple to find. It is enough to lay out servers which deal with the available services. As these servers are always accessible, it is only necessary to ask them to obtain the address of the host which can provide the required service.

In ad hoc networks, such centralized data is unsuitable. Indeed, servers which provide required services may be inaccessible due to user mobility. Keep in mind that the network only consists of mobile entities, and that of small size. This means that there is a considerable probability that a machine in the network may not have the capacity in term of memory, energy, and band-width that allows it to support all available services and to respond to the requests of all other network members. For this reason, we propose methods which make it possible to distribute information across the network. This is the goal of this thesis and will be developed fully in Chapter III.

D. ORGANIZATION OF THESIS

Chapter II presents the reader with the background necessary to comprehend of the rest of the document. Ad hoc networks and their environment are presented. Then, tools

are provided which form the base of the author's contributions. Finally, the concept of distribution will be defined and the principal problems involved in information distribution will be presented.

In Chapter III, the author's contributions to the distribution of information over ad hoc networks will be presented. This chapter focuses on efficient information distribution across the network. Indeed, if the information on a service is distributed effectively across the network, it can be found simply by carrying out more localized research, without overloading the whole network.

Chapter IV presents the statistical results obtained from the different cases done and provides detailed statistical analysis on the results.

Finally, Chapter V concludes the research and provides suggestions for further research.

II. BACKGROUND

A. OVERVIEW

This chapter will allow the reader to examine in depth the world of telecommunications, and especially ad-hoc networks. After a brief review of the pioneers who developed powerful, indispensable technologies, the author will compare current research trends in building communications networks. The author's description of ad-hoc networks will provide the reader with the necessary basis for understanding what follows in this thesis, and will make the reader aware of the problems inherent in this work.

B. AD-HOC NETWORKS

1. Definition

The simplest way to define an ad-hoc network is as a network with completely decentralized control, where the objects communicate by the intermediary of a wireless interface. It is understood that a fixed infrastructure is not required in such a network; on the other hand, such a network uses local information in the decision-making functions of the various protocols and algorithms.

2. Applicable Domains

Historically, military forces were the first organizations to use ad-hoc networks. In the 1970's, the DARPA (Defense Advanced Research Projects Agency) proposed the creation of a Packet Radio Network [4]. This protocol

makes it possible to deploy a communication mechanism between different units via vehicles, which communicate via a radio connection.

This research considered the various fundamentals related to this type of networks and their limitations. Many points discussed in this work, as well as some of the solutions proposed, remain interesting more than twenty years later. However, this protocol also has many weaknesses, in particular, regarding the mobility and the size of the equipment. This protocol is based on the assumption of slow movement and minor changes of topology. Moreover, the electronic technologies of the 1970's make the equipment heavy and difficult to use.

The military's interest in this technology is explained by ad-hoc networks' adaptability to hostile situations. Because the network is auto-organized and does not require an infrastructure, it can be deployed quickly, without difficulty, and while offering good fault-tolerances. This means that ad-hoc networks can be used even during disasters such as hurricanes or earthquakes [5]. The technology allows rescue teams to communicate even if the traditional communications infrastructure has been destroyed, and permits survivors to establish a network which allows them to be found more readily. Moreover, the possibility for communications to take several paths reinforces the reliability of such a network, which is essential in such a context.

It is obvious that, in a commercial context, ad hoc networks can also be used to form local area networks. Network installation is simple, with no cable to be plugged

in the building, resulting in an advantage for a communications company. In the case of temporary situations such as holding of a conference it is simple to setup an ad hoc network, again, because wiring is not required.

Within the framework of omnipresent data processing (as described by Mark Weiser [6]), ad-hoc networks can be used for connecting all the equipment in a house or for establishing the links between the various data-processing components of clothing (Wearable Computing [7]). This framework refers not to a LAN (Local Area Network), but rather to a PAN (Personal Area Network). In this case, the ad-hoc routing can be utilized to link all the elements with equipment with low power, and short range (which is an advantage in terms of power consumption).

Finally, ad-hoc networks prove to be very useful hostile environments. In this case, they are used in sensor networks [8, 9]. Sensors, charged to measure the physical properties of the environment (like the temperature, pressure...), are dispersed (most often released from a plane or a helicopter) by the hundreds, or even by the thousands, take their measurements, and send the results to a station via ad-hoc routing through the network. The principal characteristic of such an application is the limited energy, memory, and processing capacity of these devices.

Ad-hoc networks have very broad potential in the near future, which will generate increased interest in research on this field. However, many challenges must be addressed before this type of network can be used in all the applications referred to above. The rest of this chapter

will outline the principal limitations of ad-hoc networks, as well as existing solutions. First, the existing differences in managing access via the radio medium and the access via wired medium will be examined. Then, the problem of transporting a station's packages to one (point-to-point routing) or several (diffusion) stations will be considered. Finally, this chapter will conclude by discussing the aspect which will be the focus of the rest of this document, that is, information distribution via the ad-hoc networks.

3. Modeling an Ad-Hoc Network

In the majority of case studies (and in particular in the present document), an ad-hoc network can be modeled as a unit graph $G = (V, E)$ [10], with V the whole nodes of the graph (each station of the network corresponds to a node in the graph) and E the whole arcs giving the direct possibilities of communication between the stations (in this document, it is considered that communication is symmetrical, thus, the corresponding graph is not directed). The terms station, node, or mobile will be used interchangeably to indicate an entity forming the network. If uv is the physical distance separating the nodes u and v , and R the radius of communication of the nodes, the unit E is defined as:

$$E = \{(u,v) \in V^2 \mid uv \leq R\} \quad (2.1)$$

C. AD-HOC ENVIRONMENTS

Fulfilling the requirements of the applications described above poses many challenges, largely as a result

of the distributed aspect, and the use of wireless communications interfaces in ad-hoc networks. To obtain a working environment with a quality equivalent to that provided by the wired world would seem very difficult. Indeed, many obstacles will cause the failure of naive attempts at the adaptation of existing protocols.

First, the quality of the link provided by a wireless connection has no direct equivalent in common with a wired connection of a type such as Ethernet 802.3 [11]. In addition to the obvious difference in flow (54 Mbps for 802.11g [2] and 1 Gbps even 10 Gbps for wired [12]), the variation in the stability of the link is even more crucial. In a wired network, a theoretical flow can be reached without any problem; with a radio connection, flow, as well as delays will be strongly dependent on the environment. The materials constituting the walls, the time that it takes to build the network and various parasitic apparatuses will largely affect the quality of the radio operator link. Moreover, as will be seen further along, the access to the medium is much more complicated in the case of a radio operator link.

Secondly, the term network distribution makes the majority of traditional protocols not adaptable. If we take the example of routing (essential in a network) a simple routing IP cannot be carried out. So, the question that should be asked here is: Which objects would endorse the role of routers? Moreover, as objects use a wireless connection, the latter users can move and continue to profit

from the advantages of connection. It is not possible to consider using routing based on static tables as in the case of IP.

The techniques which were previously presented will now be discussed in order to solve the problems of access to the radio operator medium, the diffusion of information in the entire network, and the routing.

1. Access to Media

a. Limiting Media

A radio communication interface makes it possible for users to access a network easily while being mobile. Nevertheless, this immense advantage suffers from important disadvantages that limit the flow available to users. The use of the airwaves as a means of communication is under strict regulation, which prevents unlimited frequency access. Thus, it is impossible to increase the flow in order to meet increased demand. In the wired world, it is enough to add a wire or an optical fiber to increase flow.

Despite that, there is a problem which is common to both worlds, that is, the division of access to the medium. Indeed, if two users want to transmit at the same time on the same medium (air or wire), there is a collision. In the best case, only one of the two communications will be usable. In general, both communications will be obstructed, which decreases the flow (because of delays) and in the case of portable peripherals, wastes energy.

b. Protocols without Collision

Many protocols were developed in order to provide an equitable division of channels and to completely avoid collisions. An example of these protocols is networks based on a token ring [13]. A token circulates in the network from station to station. The station which has the token can transmit its data. Because it is the only one to have the token, nobody else can transmit at the same time. Once the transmission is completed, the token is passed to the following station. Figure 2.1 show how such a network is structured.

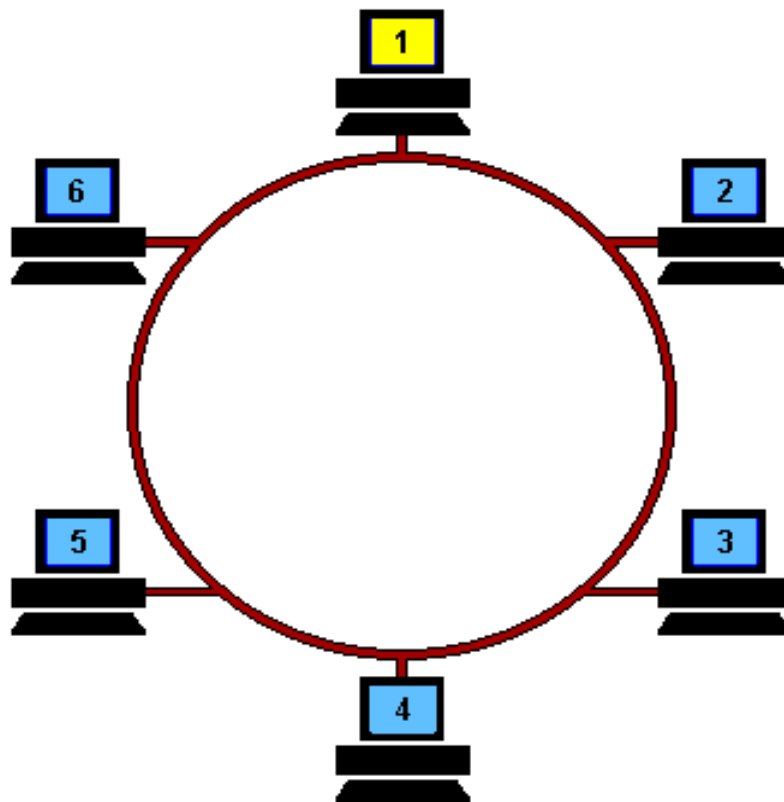


Figure 2.1. A network based on a token ring (From [14])

This type of architecture is known as "without collision." Through synchronization the stations sharing the channel collaborate in order to not produce any collisions. Other examples of algorithms without collision are TDMA (Time Division Multiple Access) [15] or FDMA [16] (Frequency Division Multiple Access) algorithms. In the first case, time is divided into intervals and each station is assigned a time slot. A station that wishes to transmit will be the only one using the slot allocated. In the second case, each station is assigned an emission frequency. Thus, the stations can transmit at the same time without collision with the rest of the stations. In the case of a GSM [1], for example, the two techniques are mixed. The channel is divided into sub-frequencies (FDMA), which are divided into intervals of time (TDMA).

The advantage of such access methods is that the collisions do not even exist, and that the distribution of channels is perfectly equitable. On the other hand, it is necessary to synchronize stations, which is very difficult to do through distribution. Moreover, if certain stations do not have anything to transmit, there is a waste of available band-width because the portion of the channel which is reserved for them cannot be used by any other stations.

In order to avoid the need for such synchronization, as well as to prevent the loss of effectiveness that arises when stations do not have anything to transmit, there are methods of channel management that rely on multiple levels of access. A station that needs to transmit will be able to do it immediately, without needing

"to wait its turn." The goal of these multiple access channel management protocols is to minimize collisions.

c. Protocols with Multiple Accesses

In the 1970's, Abramson developed the ALOHA protocol [17]. The basic idea of this protocol is simple: let user's access channels freely when they have data to transmit. Under these conditions, it is clear that collisions can and will occur. By listening to the channel during transmission, the user can know if a collision is occurring and, in this case, retransmit the packet. In order to improve the capacity of ALOHA, Roberts proposed in 1972 [18] dividing time into slots, or intervals, with each interval corresponding to a packet. This technique requires that stations be synchronized but it reduces the vulnerability period of the packets. Nevertheless, the principal problem of this method remains that a transmitting station transmits its packet when it wishes, without being concerned about knowing if the channel is free at that time.

The protocols based on the fact that the behavior of stations is determined by the result of listening to channels are known as carrier sense protocols. In 1975 [19] Kleinrock and Tobagi analyzed several protocols belonging to this family: CSMA 1-persistent (Carrier Sense Multiple Access), CSMA-persistent, and CSMA p -persistent. The difference among these protocols resides in their reaction to an occupied channel. The first (1-persistent) listens continuously to the channel, and transmits as soon as it is released. The second (non-persistent) stops listening to the channel for a random time, then tries to transmit another time. For the last type (p -persistent), the station

transmits its packet only with a probability p when the channel is free. If the channel is occupied, the station proceeds as in the non-persistent case.

These protocols constitute an improvement over ALOHA because they ensure that the stations will not emit if there is another station that already emitting. Another improvement is that if a station detects a collision it immediately stops its transmission, in order to release the channel as fast as possible. Moreover, this makes it possible to re-transmit the lost packet. This algorithm is known as CSMA/CD (Carrier Sense Multiple Accesses with Collision Detection) and is used by Ethernet 802.3 [11].

If two stations detect a collision at the same time, they are likely to retransmit the package at the same time, and generate a new collision, and so on. To moderate this problem, Ethernet uses an algorithm of random waiting (or stochastic). The stations which detect a collision make a random latency before re-transmitting the message. The time taken is between 0 and T_{MAX} . If a collision occurs again, time T_{MAX} is doubled. The more collisions occur, the longer stations will wait before re-transmitting, which makes it possible to decrease the use of the channel and so able to retransmit with fewer collisions.

d. Access to Radio Interface

Like Ethernet, there are methods which access a radio interface randomly. However, CSMA/CD is not directly applicable in the case of a wireless interface. Indeed, various problems make the installation of CSMA/CD impossible. First, the majority of interfaces being half-

duplex do not listen to channels during transmission. Thus, collisions are no longer detectable. Second, certain situations related to the range of communication of the interface invalidate the principle of listening to channels before transmission. These two particular situations are called a hidden terminal problem and an exposed terminal problem.

(1) Hidden Terminal Problem. This problem is illustrated in Figure 2.2. In this case the scenario is station A transmits a packet to station B. Station C also wants to transmit a message to B. If it uses a CSMA type algorithm, it will listen to the channel to know if it is free or not. For C, the medium seems free near the transmitter, and so will think that the channel is free. It emits its packet, but this will collide with the packet that A is sending to B. Thus, C does not know if A is emitting or not because it is "masked" by the lack of range of communication. If it emits, there is a collision on the level of the message receiver.

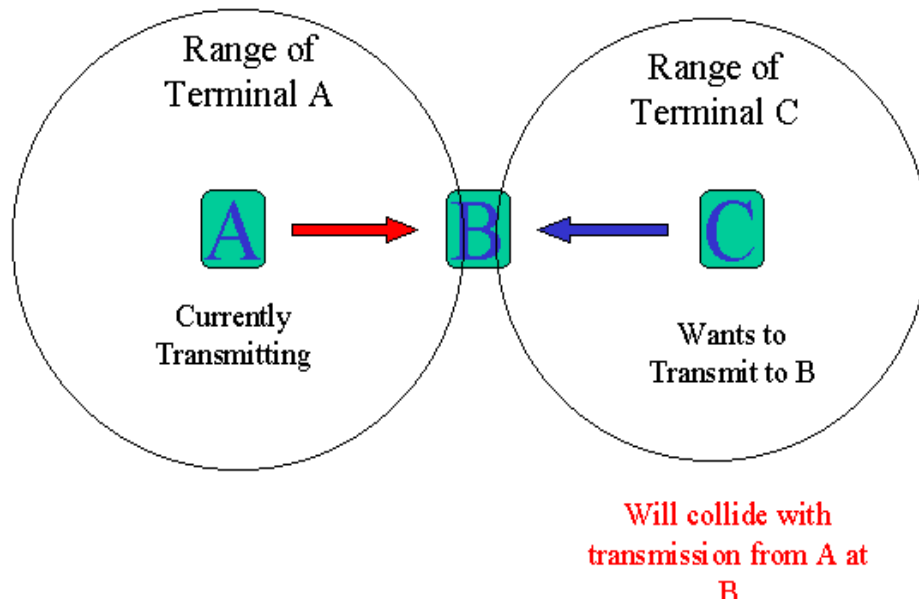


Figure 2.2. Hidden Terminal Problem (From [20])

(2) Exposed Terminal Problem. The problem, illustrated in Figure 2.3, is the reverse of the one detailed above. Here, station B transmits a message to station A. During this time, C wishes to communicate with D and listens to the channel. It hears B (because it is in the range of communication) and does not transmit its message to D. Thus, this transmission would not scramble the mobile A because it is not in the range of C. The productive flow is decreased because C does not emit although it could.

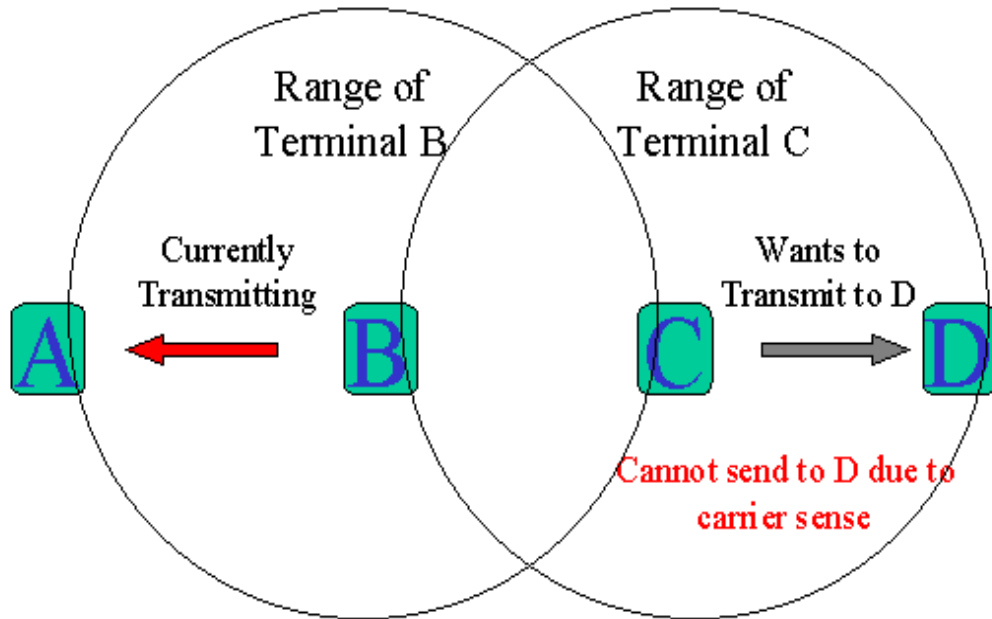
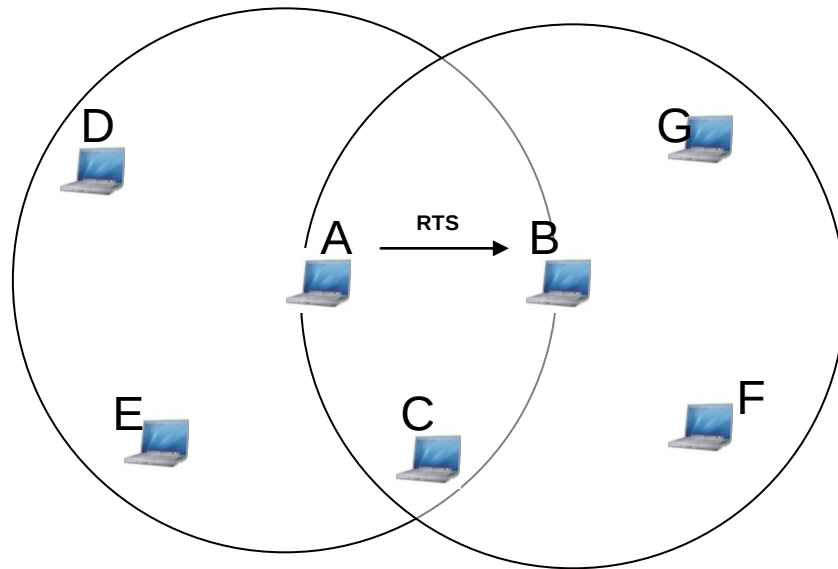
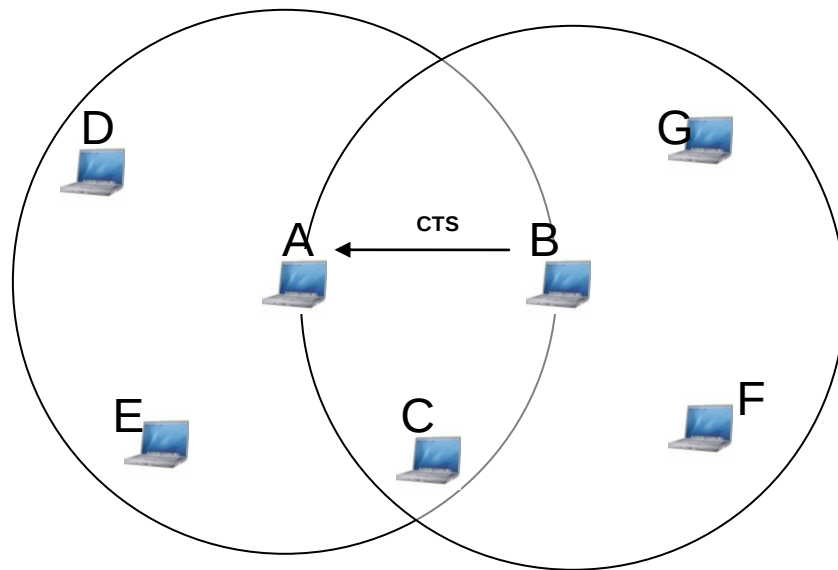


Figure 2.3. Exposed terminal Problem (From [20])

(3) MACA and MACAW Protocols. One of the first protocols conceived for wireless local area networks is MACA [21] (Multiple Accesses with Collision Avoidance). The transmitter sends a small packet, or RTS (Request To Send), which has little risk of generating a collision, in order to warn its neighbors as well as the receiver. The receiver responds to this packet with CTS (Clear To Send). All the stations which receive the RTS or the CTS avoid transmitting data during a time specified by the RTS and the CTS (which depends on the size of the packet to transmit). This procedure is illustrated in Figure 2.4, where station A sends a packet to B. Because of the RTS, C, D and E will not interrupt the transmission and because of the CTS F, G and C will not interrupt either. This exchange of packets makes it possible to manage the hidden terminal problem, as illustrated in Figure 2.2.



(a) A sends an RTS to B



(b) B answers with a CTS

Figure 2.4. MACA Protocol

After analysis of the MACA protocol's weaknesses, Bharghavan et al. optimized it, giving rise to the MACAW protocol (MACA for Wireless) [22]. In addition to again employing the principle of RTS and CTS packets, the authors initially observed that without acknowledgement in the connection

layer, stations detected only the last packet that was transmitted (using an acknowledgement in the transport layer, for example). To remedy this situation, they added the step of sending an acknowledgement packet (ACK) after the data packet. They also decided to use CSMA to prevent the RTS or CTS packets from conflicting with another communication. Using CSMA also permitted them to manage the stochastic principle of waiting, in case of transmission failure by a few stations, rather than by a single station, which would make the protocol more equitable.

(4) MAC Layer of 802.11b. The principal commercial product available is WiFi which implements the standard IEEE 802.11b [2]. With regard to the MAC layer, the standard presents two operating modes. First is the so-called ***Distributed Coordinated Function***, or ***DCF***, which does not need a centralized control entity, and which can be compared to Ethernet. The second, called ***Point Coordination Function***, or ***PCF***, is used in the case that an access point is available. This last mode is optional, but all implementations accept the DCF mode. In the PCF mode, the access point asks the stations if they have something to transmit; this can be carried out by an access point as well. As a result, there are no collisions in this mode.

The DCF mode uses the CSMA protocol with collision avoidance, or CSMA/CA (CSMA with Collision Avoidance). This protocol is also divided into two distinct uses, diffusion or point-to-point. In the first case, the station wants to emit a packet to all its neighbors. It starts by waiting a minimum time, called DIFS (DCF Inter-Frame Spacing), in order to give the other stations a chance

to use the channel. Then, it picks a random number which represents the time during which the channel must remain free before it can transmit its message. If, after this time, the channel remains free, the station can emit its packet. In the second case (point-to-point transmission), the CSMA/CA protocol is based on MACAW and uses the same principle of listening to the channel as in the case of diffusion, plus the RTS, CTS and ACK mechanisms.

(5) Bluetooth. This system was originally developed by Ericsson, IBM, Intel, Nokia, and Toshiba with the aim of connecting cell phones to other types of equipment. Although the first goal was simply to remove the cables between equipment, the success of the standard led it to be used within the framework of wireless LAN. The general principle of access to the medium is a system of the TDMA type where a Master gives instructions to slaves in their allotted slots of time. This explains the very low flow (1 Mbps) of Bluetooth equipment. This low flow, as well as the Master/slave operating mode, makes Bluetooth slightly better adapted to the context of ad-hoc networks.

2. Routing

Routing is considered the key mechanism of ad-hoc networks. Through the mechanism of routing, the stations forming a network will be able to communicate even if they are not within same range of communication. Thus, it is very important to have an effective routing protocol in order to benefit from the potential of ad-hoc networks. However, if in the case of wired networks such as the Internet, routing is simple, the situation is quite different with ad-hoc networks. In the wired world inter-router connections are

considered static and can be stored in routing tables which are rarely modified. In ad-hoc networks, mobility requires constant modification of these routing tables. Moreover, in ad-hoc networks, it is necessary that all stations function as routers because if not, it will happen that a station could not have a router in its vicinity and thus be unable to communicate with the rest of the network.

If station A wants to join station B on the Internet, the path that supports the packages is known at the beginning of the communication, and will remain the same throughout the entire period. In an ad-hoc network, station A does not know where B is and even if it finds it, nothing guarantees that B will be at the same place a few seconds later. The two vital operations of routing in an ad-hoc network are the search and the maintenance of paths, because during communication, mobility will cause some changes between the source and the destination stations.

Finally, and again because of mobility, it may be that no path is available between two stations and thus these stations are physically disconnected. Contrary to the case of a wired network, where a disconnection constitutes a real breakdown, this can be considered a normal event in an ad-hoc network.

There are three great families of protocols of ad-hoc routing: re-active, pro-active, and hybrid protocols. The detailed description that follows includes the most commonly known protocols, but omits geographical routing algorithms, which will be treated in Chapter III.

a. Pro-active Algorithms

This type of algorithm consists of maintaining information that will be used to find a path towards a given station. The principle can be understood through the Bellman-Ford routing protocol [23], used to update Internet routers. Each station of the network maintains one or more tables which enable it to know in which direction to transmit a package, according to the required destination. When the topology of the network is modified, the stations will diffuse the modifications perceived in order to update the information contained in the tables. There are several algorithms of this type, which are differentiated by the information used in the tables, and the methods of updating these tables.

The DSDV (Destination Sequenced Distance Vector) protocol [24], developed by Perkins and Bhagwat, maintains a table containing, for each destination, the neighbor to join a node, as well as the number of hops and the sequence number. The algorithm considers a path P_1 better than a path P_2 if it has a more important sequence number (i.e., the path is more recent, allowing information to likely be more correct) or if the sequence number is the same, but the distance estimated towards the destination by taking the path P_1 is weaker than P_2 . Each station transmits its routing table regularly and increments the sequence number corresponding to the path that leads to it. When a station estimates that its path towards another is occupied, it updates its routing table with an infinite distance. In order to diffuse the table's updates, the station can emit two types of packages: the complete table (full dump) or

only the parts of the table what were modified (incremental), in order to reduce the use of the medium.

Murthy and Aceves proposed the WRP protocol (Wireless Routing Protocol) [25]. The principle is identical to DSDV but uses, in addition, information about distance and information age, the concept of cost of path (in term of latency between a station and various destinations). Each station periodically transmits its routing change table, as well as requests for confirmation of its presence to its neighbors in order to inform them of the topological changes and to check the validity of its vicinity.

The CSGR (Cluster Switch Gateway Routing) protocol [26], presented by Chiang and his partners, centers around an architecture based on regrouping stations into clusters. Each one of these clusters has a leader which undertakes the communications inside its own cluster and maintains routing information allowing it to join the leaders of other clusters. This approach is interesting because the stations of the same cluster move slightly away from each other, due to little change in the topology of the cluster. For example, such a routing protocol can be adapted perfectly to a situation of PAN (Personal Area Network). However, if the clusters require frequent modification because of mobility, this approach will be too expensive for updating information frequently.

One of the most interesting proactive protocols is without a doubt OLSR [27], a protocol resulting from INRIA which is standardized by IETF [28]. This algorithm is designed to minimize the cost associated with control messages. Each station regularly calculates the MPR subset

(Multi-Point Relaying) [29] of its neighbors. The MPR set is the neighbors necessary to join other neighbors within two hops. Thus, during the diffusion of the control messages which construct the routing tables, only the stations belonging to the MPR set will be used to relay the messages; they are also used to build the paths.

The principal goal of these pro-active algorithms is to quickly and easily find the destination without needing to launch a search within the network. Moreover, information collected to contribute to routing can be very useful for other applications and, if information is regularly updated, losing paths is not frequent.

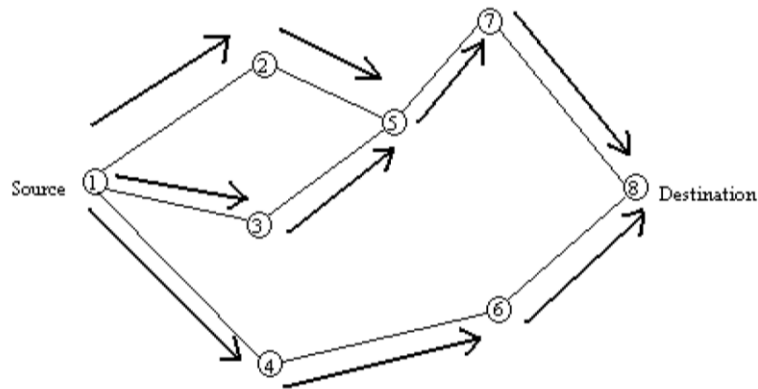
However, these algorithms are dependent on regular and reliable updates to information, which induces a constant network load, due to control messages. In the case of networks with high mobility, this load proves to be catastrophic because the totality of bandwidth is devoted to control messages and leaves other applications without enough resources. Moreover, if the network is very large, the quantity of information to be diffused and memorized also becomes a problem.

b. Re-active Algorithms

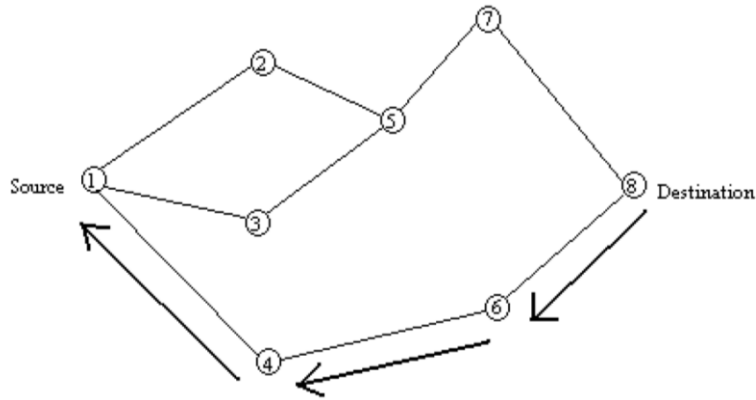
Reactive algorithms pursue a policy opposite to that of pro-active algorithms. Here, no regular maintenance is carried out and the search for paths is done only by request. When a station seeks to join another, it uses a diffusion protocol (sending a message to the entire network) in order to discover the path to reach it. When the correspondent receives the diffusion message, where the list

of stations is stored that were used to convey this message, it can answer by a message which will follow this same path in order to inform the source. Figure 2.5 gives a simple example of such a procedure.

The best-known reactive algorithm is AODV (Ad Hoc One-demand Distance Vector) [30, 31]. In this algorithm, the path traversed by the research packet is not preserved in the packet itself, in order to minimize its size. Each instance of research is identified by a sequence number and the relays used at the research of the path memorize the preceding station. During the response, each station validates the path to which it is relayed.



(a) Propagation of Route Request (RREQ) Packet



(b) Path taken by the Route Reply (RREP) Packet

Figure 2.5. Route discovery in AODV (From [32])

The DSR (Dynamic Source Routing) protocol [33], proposed by Johnson and Maltz, is very similar to AODV. The principal difference lies in the search level of a packet and in the response during which, contrary to AODV, the path to be followed is memorized. Moreover, this protocol manages the asymmetrical links. This refers to a situation which corresponds to a difference in the strength of emission between two stations A and B, implying that B can hear A but reciprocally, A cannot hear B.

Other protocols, such as SSR (Signal Stability Routing) [34] or ABR (Associatively-Based long-lived Routing) [35] introduce the concept of path reliability (respectively by taking the quality of the signal in reception into account, or the topological changes of the vicinity). During construction of the path, the diffusion is skewed in a way to follow the links that have a high degree of reliability.

This class of algorithms seems to be effective in large networks and/or those with high mobility. Indeed, as the paths are built by request, a constant and important

load network, due to changes in network topology, is avoided. On the other hand, if the algorithm used at the stage of diffusion is ineffective, the performance of these algorithms can become extremely bad.

c. Hybrid Algorithms

The principle of hybrid algorithms is to combine two algorithm approaches in order to benefit from the advantages of both principles, while compensating for their disadvantages.

The TORA (Temporally-Ordered Routing Algorithm) algorithm [36] focuses on establishing a directed acyclic graph of which the root is the destination (i.e., the node destination is the only node without an outgoing arc). Thus, from each station, one can find the destination by following the orientation of the graph. This algorithm is a distributed algorithm, whose version turns on each station and for each destination. The routing can be seen as fluid flowing in tubes. Each tube represents a connection between two nodes, the junction between two tubes is a node, and the fluid that runs out represents the packages. Each node has an attribute, such height and the amount of fluid that will run from the highest level to the lowest level. If it is blocked at a node, the height of this last is increased such that it is higher than that of its neighbors and the liquid can continue its race. When a node needs a path towards a destination, it emits a query packet containing the address of the destination. This packet is propagated in the network until it arrives at a node close to the node destination. This emits an update packet containing its height (the height of the destination is 0, its will be 1). When a node

receives the update packet, it allots a height higher than that contained in the package, which causes it to direct the graph's arcs in order to have a path towards the destination for all the nodes of the network. When a packet of data needs be transmitted, it will follow the graph according to the difference between its height and the height of its neighbors.

When a node discovers that the path towards its destination is no longer valid, it readjusts its height and transmits an update package to update the graph. The knowledge of downward arcs (i.e., the height of the neighbors) is obtained by regular diffusion of information height by the nodes. This algorithm is mainly reactive (because it builds the path by request) but has a proactive part (the update of the arcs) which makes it possible to optimize this research.

Figure 2.6 shows the different steps to search a path. The pair (H_i, I_i) of each node represents the height (H_i) and the identification (I_i) of this one.

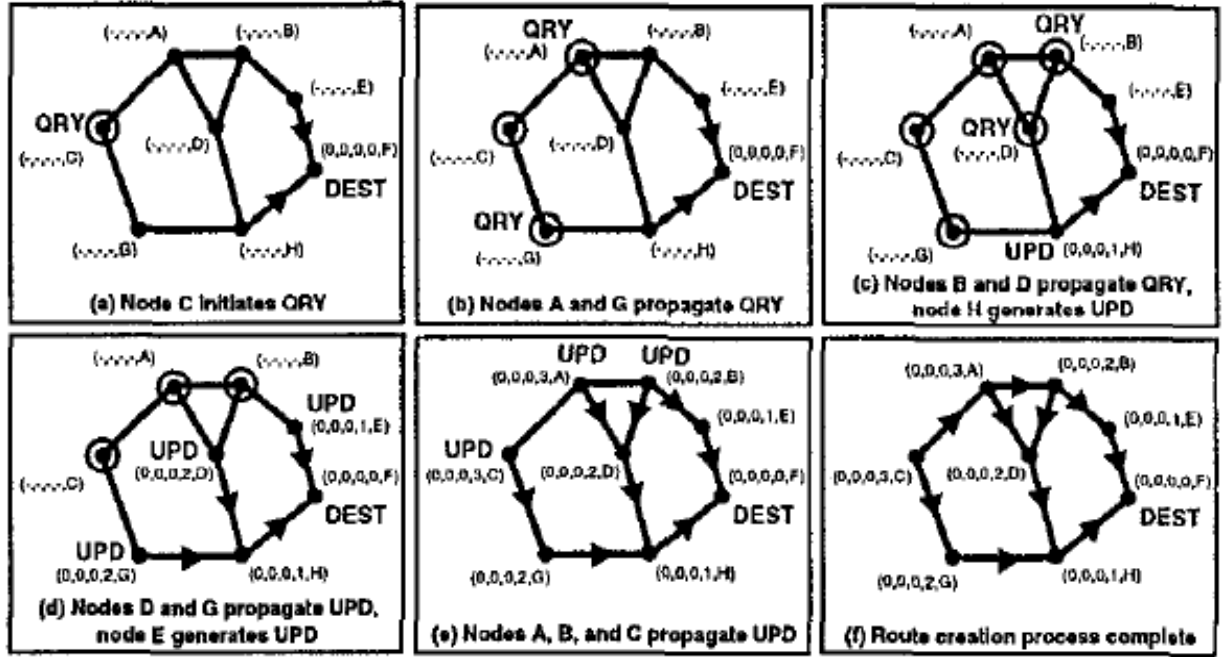


Figure 2.6. Creation of a path by TORA Algorithm (From [36])

The ZRP (Zone Routing Protocol) protocol [37] uses a proactive protocol to join the stations located at a distance lower than k hops and a reactive protocol for routing between groups (or routing zones). Each station knows (because of the proactive aspect of the algorithm) how to join the other members of its group. If it must join a node that does not belong to this group, it uses the IERP (Inter-zone Routing Protocol) protocol [38] to send a request to the stations located at the edges of the group. Then these transmit the message to the edges of the nearest zones, and if the destination belongs to one of these zones, the path uses a proactive protocol again to reach the destination.

As mentioned during the description of protocols (whether reactive, proactive, or hybrids), it is very often

a question of a diffusion algorithm. The quality of these algorithms can largely modify the performances of the routing and they form a paramount field of study for the efficient of the routing algorithms. Moreover, such algorithms can also be very useful in the application field and particularly, in our concerns, for the information distribution.

3. Diffusion

Diffusion is the operation of sending a message to all the members of the network. Many algorithms were developed to deal with this operation by trying to limit its cost as much as possible. The quality of an algorithm of diffusion will depend on various criterions:

- Reliability or capacity: This aspect joins all the stations of the network. A reliable protocol makes it possible to join the totality of the network if this one is connected.
- Power consumption: In the case of a context where the energy of stations is limited (because they use batteries, for example), it is important to consume the minimum possible. This consumption will be frequently a function of the number of emissions of a diffusion message.
- Average latency: This represents the average delay between the beginning of diffusion and the last reception of a diffusion message.

The simplest algorithm is blind flooding. Its function is trivial: each station retransmits the diffusion message if it receives it for the first time. The implementation is also very simple; the source inserts in the message of diffusion a sequence number which must be unique for each diffusion. Each mobile receives the diffusion message seeking the sequence number of this last one in a table. If

it is not present, it retransmits the message and inserts the sequence number in the table. Otherwise, the device disregards the message because it is already received. While the simplicity of the algorithm can make it attractive for primary access; its naiveté makes it extremely expensive and difficult to use if we want to obtain reasonable performance. Indeed, all the stations will transmit a message at least once which, generally, seems useless. Even with a low network density, it is obvious that many mobiles will have common neighbors who, if each mobile transmits a diffusion message, will receive the same information several times. Moreover, as all the neighbors of a mobile will try to retransmit at the same time, the congestion generated on the MAC layer is extremely likely to become catastrophic! This problem is referred to as the Broadcast Storm problem, analyzed by Tseng and his partners [39]. They propose various modifications bringing improvements to the basic algorithm, making it possible to decrease any negative impact. Here is a brief overview of the modifications suggested:

- Probabilistic diffusion: Each mobile with a probability p , fixed at the beginning to retransmit the message
- Diagram based on counting: A mobile does not retransmit the message if it already received it more than N times (also fixed at the beginning)
- Diagram based on distance: A mobile does not retransmit the message if it receives it from another mobile located at a distance lower than D (always fixed at the beginning)
- Diagram based on position: With positioning information provided by a system of the GPS type, a mobile does not retransmit the message if it can

join a sufficient number of neighbors located further than it from the source

- Diagram based on groups: The network is organized in a hierarchical way in several groups and only certain mobiles belonging to a group retransmit the message

This work provided an excellent base for work on diffusion and many approaches were proposed.

As has been seen in this chapter, much research focuses on the proposal of new protocols to fulfill the functions of the low layers of the OSI model [16]. On the other hand, if the routing, MAC access, or diffusion constitute vital protocols, it is obvious that it is also necessary to concentrate on the applicative problem. Indeed, these applications create the need to have a functional network. The end of this chapter will be devoted to the presentation of the concept of information distribution, as well as various tools to facilitate the design and the use of this information in a network.

D. CHAPTER SUMMARY

This overview of ad-hoc networks presented their various key components such as applicable domains, modeling, access to media (limiting medium, protocols without collision, protocols with multiple access, and access to radio interface), the different routing protocols, including pro-active, re-active and hybrid algorithms, and information diffusion.

The next chapter will cover previous research and will present the author's contribution to solving the problem of distributing information in ad-hoc networks.

III. INFORMATION DISTRIBUTION

A. OVERVIEW

In this chapter, we present our approach to resolving the problem of information distribution in ad-hoc networks. Our focus is on the problem of data diffusion from a general point of view. The solution suggested will be applied to various applications such as searching for services, geographical routing, or any other application requiring the data distribution in the network in order to maximize availability from the greatest number of nodes.

B. OBJECTIVE

In network architectures, such as CORBA [40] or Jini [41], the search for services is managed by a central server. Each new service is recorded by the server, which will then supply the identifier of the service provider if an application requires it.

Within the framework of ad-hoc networks, this solution, or in fact any centralized solution, is not applicable. There are several disadvantages to the use of centralized architectures in an ad-hoc environment:

- Objects that are far from the central server are penalized, as the time needed for routing the request increases relative to distance;
- Requests are always made near the same server, which thus becomes a critical point in the network. In addition, if this server is a mobile object, it becomes difficult to locate;
- Finally, if the server breaks down, the whole network is penalized.

To deal with these problems, the ad-hoc community has proposed distributed versions of traditional centralized protocols. For example, within the framework of required services, it is both useful and effective to distribute the knowledge of available services across the whole network.

Because mobile data processing frameworks have little or no fixed access, it is difficult to visualize a way to distribute information so that it is located near applications which are in use. Moreover, the objects considered are subjected to certain constraints (which do not exist in wired networks) such as low memory capacity and limited energy reserves. If these constraints are not considered, it is possible to create an ideal distribution where each object would be informed of all information available in the network. However, a realistic and effective solution would limit the number of objects that are aware of information and distribute it in a manner which decreases search time.

In this chapter, we propose an algorithm which allows satisfactory distribution of information among the objects forming a network. This algorithm is based on an effective principle of information distribution which accounts for the distance covered by information requiring distribution.

C. PREVIOUS WORK

Distributing information across the network is mainly used to discover services and to research the position of an object for geographical routing. Another interesting aspect of information distribution is the various cache policies which can be used to manage memory in an effective manner.

1. Discovered Services

Mobility imposes regular information updates on objects. The discovery of the environment and services which are at the disposal of objects is difficult to accomplish because of the absence of fixed infrastructure which characterizes mobile networks.

Before discovering this information, it is necessary to distribute this information (or knowledge of it) through the network. Effective information distribution reduces the number of transmitted messages needed to discover this information, as well as shortening query time.

Some previous studies have dealt with discovered services without considering effective information distribution. In [42], for example, the authors propose organizing the available network services in clusters, which are then arranged in layers. The clusters are formed according to the physical proximity of the nodes with information and to the semantic proximity of the information possessed by the various nodes of the network. The goal of this approach is to facilitate document retrieval through the network.

Several proposals for protocol standardization for discovered services were made by various industrial organizations. Consider Jini [41] from Sun, SLP (Service Location Protocol) [43] from the IETF (Internet Engineering Task Force), UPnP (Universal Plug and Play) [44] from Microsoft, Salutation [45] from IBM, or SDP (Service Discovery Protocol) [46], and Bluetooth's discovered services protocol. Jini's principle, for example, is based on a lookup mechanism which searches for a service. The

servers record the services which they provide in a directory. SLP functions with a similar principle: the servers record their services near one or several DA (Directory Agents). This type of centralized architecture is not appropriate for ad-hoc networks, since connection with a central object is difficult to maintain [47].

The routing protocols Ad-Hoc On-Demand Distance Vector Routing (AODV) [30] and Dynamic Source Routing (DSR) [48] version unicast are reactive protocols (the paths are built with the request); an emitted packet is intended for a particular node. These two protocols are efficient in terms of the number of control messages sent. For example, the DSR protocol is considered one among the best protocols in domain ad-hoc networks because it reduces delays, as well as resulting in greater bandwidth and energy efficiency. Despite these advantages, DSR also has some disadvantages such as overhead (large headers), particularly when the data content of a packet is small. AODV was created to improve DSR by maintaining routing tables at the nodes, so that data packets do not need to contain routes. AODV maintains the advantageous aspect of DSR, in that routes are maintained only between nodes which need to communicate. Another advantage of AODV over DSR is that nodes use routing tables with entries only for routes that are in use. DSR may maintain more than one route for a single destination, but AODV maintains only one route for each destination.

In [49], the authors propose a performance evaluation of several publication and request strategies. A few publication and request strategies are carried out around publication protocols and associated requests.

Servers publish the services which they provide and users request services that they need, according to the protocols' publication and the requests used. The strategies confronted are:

- a glutton strategy
- an incremental strategy
- a memory-less strategy
- a memory strategy
- a modest strategy

The evaluation of these strategies is carried out in successive rounds. In each round, a server publishes a service and a user researches it. With each round, the strategies can modify their behavior to include the preceding rounds.

In a glutton strategy, the server publishes the service on all nodes, and the user seeks it on all others (broadcast algorithm).

In the case of an incremental strategy, for each round, the server extends the zone in which it publishes the service. In the same way, the user who makes his request extends the zone of the latter for each round.

In a memory-less strategy, the server randomly chooses a set of nodes and publishes its service on this set. The user behaves the same way and researches the service on a set of randomly-chosen nodes.

In a memory strategy, the user randomly selects a set of nodes for each round from among the nodes not joined to the preceding round.

When a modest strategy is used, all the nodes of a network publish services and emit requests to their neighbors located at one hop.

A glutton strategy is not appropriate for ad-hoc networks because the memory size of objects is limited; it is not realistic that all objects would know all services available in the network. Moreover, if all the nodes know all the services available in the network, it is useless for nodes to emit their requests to all other nodes in the network. Indeed, in this information distribution configuration, a request to a nearby node is enough.

A memory-less strategy can be appropriate for ad-hoc networks if the set of nodes is small and if these nodes are well-distributed throughout the network. The disadvantage is that this distribution is random and thus does not follow any reproducible diagram. The memory strategy tends towards the knowledge of all services available in the network by each node and so is not adaptable to the ad-hoc networks. A modest strategy does not provide an useful distribution of information since, in the best of cases, the nodes wishing to obtain the information published by the source will reduce the cost of the request by a single hop.

Although intended for undiscovered services, the solution suggested in [50] could well find application in this field. They evaluate heuristic replicate placement in distributed systems with a wide scale, and propose a methodology for the selection of heuristics. Constraints are introduced such as an average threshold of latency. A system of constraints is thus obtained. The originator must calculate a general lower limit and the lower limits

corresponding to all heuristic classes likely to agree with the system. The most suitable heuristic is that with the smallest limit. This approach would not be appropriate for a network of the ad-hoc type since it is an off-line approach, where the originator must configure the parameters and choose heuristics appropriate to the system with topology that modifies each time.

2. Geographical Routing

When the routing used is geographical [51], a node wishing to send a message to another must initially obtain the localization of this target node. To obtain this information, the first node can broadcast a localization request and wait for a response from a node with the desired information. Each node knows its geographical position through a positioning system like GPS (Global Positioning System) [52]. In this type of routing, if a node needs to transmit a chosen package to its list of neighbors, the nearest node to the destination would be the next hop.

Several algorithms use Distributed Hashing Tables (DHT) to determine the localization of the nodes forming a network. This is the case with both the Grid [53] and Tribe [54] localization services.

The Grid localization service (GLS) [53] is a distributed localization service. The nodes update their localization near the localization servers. Each node can play the role of localization server with respect to the other nodes. The principle of Grid is to position the network in a recursive way while following the *quad tree* principle. The space is cut into four square zones, and is

partitioned again in a recursive way until arriving at the desired minimal size. Thus, level 0 corresponds to a square of minimal size. A square of level n is composed of four squares of level $n-1$. Each node must choose a node as its localization server in each of the three zones adjacent to it in order to form a zone of higher level. Figure 3.1 shows in which zones node B will have to choose its localization servers. This distribution ensures that the more one moves away from a node, the more its localization servers are scattered. As the number of localization servers associated with a node diminishes across distance, the total number of nodes memorizing information is also minimized. A node updates its localization near its localization servers when it moves a certain distance d from its last updated localization. A node will choose as localization servers from the nodes whose identifiers are "close" to it. The nearest node to a node B is the node whose identifier is the smallest identifier higher than that of B . A node A wishing to contact node B follows the same step. It will send its request to the node it knows to be nearest to B . This node will then transmit the request in the same way and so on until reaching a localization server of B .

The principal disadvantage of this solution is that this system requires the use of GPS. This obviously does not obstruct the application for which Grid was conceived, but does prevent its use in scenarios that do not have this equipment. Moreover, it is possible that a node seeking information far from it could also find it close by. This is the case for nodes located at the edge of a zone, since the distance between a node located at the edge of one zone

wishing to reach a node close to it at the edge of a different zone and the localization server of this node is inevitably larger than that separating the two nodes.

	90	38					
70			③⑦	50		45	
91	62	5			51		11
	1				35	①⑨	
②⑥		41 ②③	⑥③	41		72	
87	44 14	7 ②	B: 17			28 10	
	98	55	61		83		②⑩
32				6	21		
81	③①	④③	12		76	84	

Figure 3.1. Example of Distribution Grid for node B
(From [53])

Tribe [54] uses the concept of rendezvous point. A node wishing to send a message to another node can find the place which stores its localization, starting from its identifier. A node updates its localization near only one node: its anchor. This node is discovered through a request. Each node in the network has a universal identifier, a virtual

identifier, a relative address, and a control field. A node calculates its virtual identifier in the addressing space starting from its universal identifier. Its anchor is then the node whose control field contains this virtual identifier. The anchor knows the relative address of the node and its current localization. When one node wishes to communicate with another, it needs to ask for its current localization. For that, it calculates the virtual identifier of the destination node by using the same calculation used to calculate its virtual identifier. It can thus find the destination anchor node. This is possible because the universal identifiers and the conversion function into virtual identifiers are known for all the nodes in the network. When a node transmits a package, it chooses from its vicinity a node where the control field is close to the control zone containing the virtual identifier of the destination.

Contrary to Grid, Tribe does not use geographical information to determine which nodes will memorize the localization of other nodes and to route packages. The disadvantage of this solution is that a given node's anchor node can be far from it. This increases the number of transmitted messages as well as request time.

3. Co-operative Caching Techniques

When a node transmits data to another node which is not its final destination, this second node can decide to preserve this data, or a reference to it, as well as the address of its destination node (making it possible to access this data more quickly). When a request concerning this data arrives at this intermediate node, it can, if it

memorized the data, quickly find the data for the node which requires it. In this way, all the nodes in the network form a co-operative caching system in which all nodes can benefit from information cached by the others. A co-operative caching technique is characterized by its policy of information memorization and replacement in the cache.

In [55], the authors propose some effective caching strategies with the goal of saving energy. They formulate the problem of cache placement like a linear programming problem. They introduce constraints such as the energy necessary for data transmission and reception. The authors mainly attempted to minimize power consumption but not cache size.

In [56], Sailhan and Issarny propose a Web data caching technique (Fig.3.2) which minimizes the energy costs of communicating among the nodes forming a network, in particular when a fixed access point is not within communication range of a node wishing to recover data on the Web.

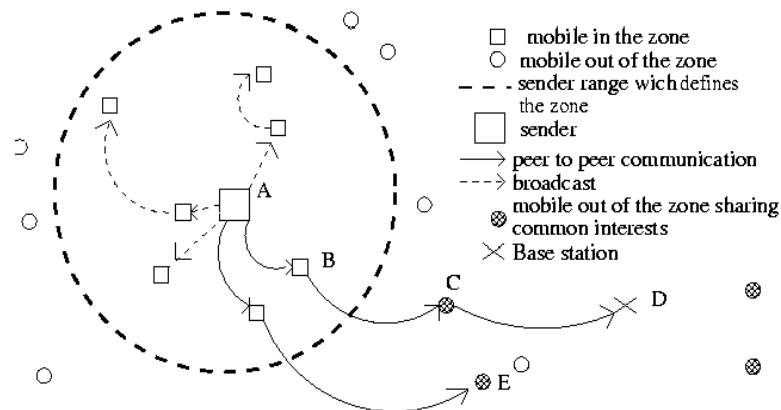


Figure 3.2. Getting Web Data (From [56])

The proposed solution provides an information replacement strategy in the cache of objects, in addition to a co-operative caching protocol. If a node is within N hops of a fixed access point to the Web, it will not contact a node with a distance higher than or equal to N to recover a document. If a node requiring a document has an access point to the Web within the range of communication, it is addressed directly to this one. If this is not the case, the requesting node will initially question its neighbors (nodes within range of communication). Lastly, it sends a request to the nearest fixed point. If a node forwarding the request to the Web access point has the document, it sends it directly to the demanding node.

Each node stores a profile of the nodes with which it corresponds to determine those that are likely to memorize useful data. Moreover, if two nodes are supposed to have a copy of the same data, the node with greater memory size will be privileged, as its data is less likely to be replaced. The local cache strategy associated with this protocol consists of measuring the probability of access to the data and the energy cost associated with its recovery. The probability of access is approximated by the number of times that the document was requested since it was cached. The energy cost associated the recovery of data depends on its presence close to the node. The consideration of document validity intervenes after the consideration of energy cost when the node's remaining energy is weak. According to these criteria, it is the less-important data which is replaced.

This solution is effective on the level of energy consumption and of search time, but it loses interest if it is adapted to an environment without fixed access points; the search for data becomes limited by Time to Live (TTL) rather than energy consumption or search time.

Yin proposes in [57] three approaches distinguished by cache settings according to:

- the data (Cache-Data)
- driving to the data (Cache-Path)
- the context of the data or of driving to the data (Hybrid-Cache)

In these three approaches, a node needing data is addressed to the node with the original copy of it. The coherence of the caches is maintained by a TTL.

In Cache-Data, the intermediate nodes relaying a message memorize the data if it was frequently requested or if they have enough memory to be able to answer future requests. To prevent several nodes from caching data unnecessarily, a node does cache data if all requests for it come from the same node.

In Cache-Path, the intermediate nodes memorize the data path to redirect the future requests towards the nearest node having the data.

In Hybrid-Cache, thresholds are established. These thresholds relate to some criteria such as the size of the data, the proximity between the intermediate node and the node with a copy, and the TTL associated with the data. If the data is of a small size, Cache-Data can be adopted because only a small part of the cache will be used to store the data. If the TTL of the data is weak, it is not

judicious to use Cache-Path since it is likely to become invalid quickly. If the intermediate node and the node with a copy of the data are very close, Cache-Path can save a great number of hops to reach the data. These approaches are effective in terms of request time and message complexity. Its disadvantage is that if nodes close to the demanding node are not directly between it and the node with the original copy of the data, they will not be detected.

The solutions implemented previously do not attend to object resources as regards memory size. Moreover, the maintenance of architectures can be difficult because of the mobility of the network. For this reason, the author has chosen to focus on a simple solution which effectively and quickly distributes information in the network.

D. DISTRIBUTION SPECIFICATION

1. Overview

Effective information distribution should minimize the number of nodes memorizing information while taking into consideration the distances covered by both the information and the request. Moreover, it is necessary to be able to carry out this process by means of a quick and simple protocol, which will make it possible to support mobility. In order to evaluate effective distribution, we propose a method which, if it is verified by the whole network, will verify accurate information distribution. We will then propose a simple distributed algorithm allowing distribution that verifies this method.

2. Principle of Distribution

Effective information distribution must consider the distances covered by the information and the request. To decrease the distance between a node with cached information and a node which requires it allows decreased time as well as cost.

In this work, we develop our idea by introducing a parameter α which will control the maximum distance separating a node that has information from a node that does not. Moreover, a node must be able to find the information required or its trace on a node nearer to the source than it is. Intuitively, the smaller α is, the greater the likelihood that the distance between a node with information and a node without will be diminished and thus, the greater the likelihood that the cost of research will also be diminished. On the other hand, the number of nodes necessary for information distribution will be larger. This is formalized as follows. Consider a node "x" that has information I_x to be distributed effectively across the whole network. Thus, this information will be in a node "y" where the distance between "x" and "y" is less than or equal to R (R is the communication range) $d(x,y) \leq R$ or there is a node $z \in V$ such that z has the information I_x and $d(y,z) \leq \alpha d(y,x)$, $d(x,z) \leq d(x,y)$ where $\alpha \in (0,1)$.

This principle reflects the fact that a node can take advantage of finding information on a node closer to it than to the source, provided that this node is less than a certain distance from it, the distance representing a fraction of its distance to the source. Figure 3.2 shows

this for a particular case where $\alpha = \frac{1}{2}$. The node "S" has information I_s and will distribute it. The node "y" verifies the principle because it is covered by the node "x" nearer to "S" than "y," the distance separating "x" and "y" being less than half the distance separating "y" and "S."

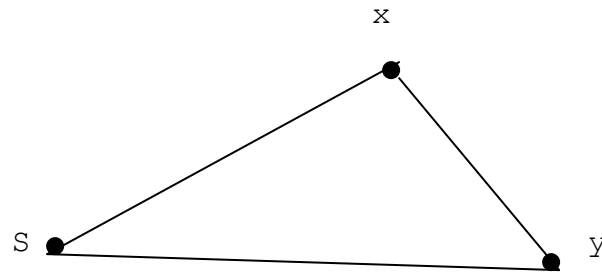


Figure 3.3. Example for $\alpha = \frac{1}{2}$

Equilibrium is attained for $\alpha = \frac{1}{2}$ since the distance separating the node ("y") seeking information from the node ("x") with information is half the distance separating it from the source ("S"). The more one moves away from the source of information, the greater the maximum distance separating a node with this information and a node without. This is acceptable because a node far from the source can agree to cover this distance to find the information which it needs. Moreover, a node distant from a source distributing information is likely to be closer to another source distributing the same information in the network.

Finding a method allowing information distribution according to this method, we first of all considered the perfect placement of nodes. In this case, it is possible to place the nodes geometrically in order to verify the principle in an optimal way.

3. Mathematical Model

Before continuing, it is important to note that for all the formulas presented in this section are deduced from geometric properties in a general way.

Under consideration here is the best possible site of the nodes with information in a graph of infinite density. Thus, it is possible to arrange the nodes as desired. This is a mathematical study. A node "x" with information covers a node "y" if it is closer to the source than "y," and if the distance separating it from "y" is less than the distance separating "y" from the source.

Now consider the information to be distributed by a node S , the information source. l represents the minimal distance from which we examine the distributed information. The nodes located inside the circle of center S and radius l : $\zeta(S,l)$ are covered by S and get information from S . The nodes located on the circle of center S and radius l are at the limits of coverage. These nodes are on level₀, within a distance l from the source. Some of these nodes will have to memorize information and thus it will be possible to extend coverage beyond level₀. These nodes will provide coverage up to a certain distance from the source.

Let a node "x" have information on level₀. Let l_0 represent the distance to the source corresponding to level₀. So, we have $l = l_0$. The set of nodes "y" at the coverage for node "x" is a circle where the center O is located within a distance L from the source and a radius R (Figure 3.4). L and R express a function of α as follows:

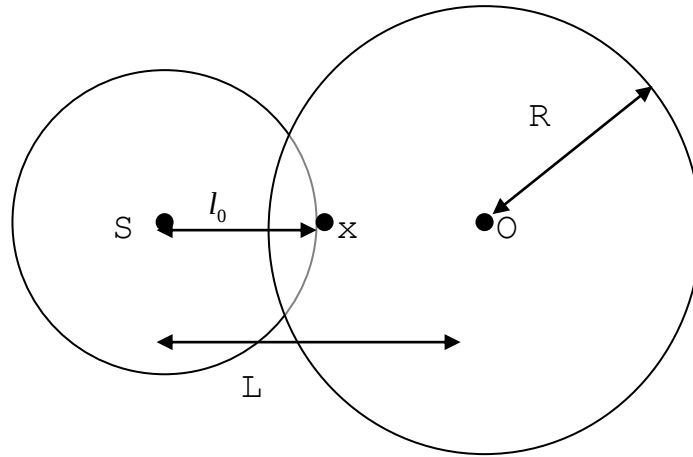


Figure 3.4. Area covered by node x

Nodes covered by node x are those located inside the circle obtained. The radius R of this circle is larger than the distance $d(O, x)$.

Determination of L and R

$$d(x, O) \leq \alpha d(S, O)$$

$$d(x, O) < R$$

$$\text{So, let } R = \alpha d(S, O) = \alpha L \quad (1)$$

Let y be the farthest node that receives information from x
Then

$$d(x, y) = \alpha d(S, y) \quad \text{so,}$$

$$R + (L - l_0) = \alpha (L + R) \quad (2)$$

Then we have :

$$\begin{cases} R = \alpha L \\ R + (L - l_0) = \alpha(L + R) \end{cases}$$

$$\begin{cases} L = \frac{R}{\alpha} \\ R + \frac{R}{\alpha} - l_0 = \alpha(L + R) \end{cases}$$

$$\begin{cases} L = \frac{R}{\alpha} \\ R(1 + \frac{1}{\alpha} - 1 - \alpha) = l_0 \end{cases}$$

$$\begin{cases} L = \frac{R}{\alpha} \\ R(\frac{1 - \alpha^2}{\alpha}) = l_0 \end{cases}$$

$$\begin{cases} L = \frac{1}{1 - \alpha^2} l_0 \\ R = \frac{\alpha}{1 - \alpha^2} l_0 \end{cases}$$

$$L = \frac{1}{1 - \alpha^2} l_0 \tag{3.1}$$

$$R = \frac{\alpha}{1 - \alpha^2} l_0 \tag{3.2}$$

Now it is necessary to determine the site (location?) of the nodes which will memorize the information to provide coverage to those nodes which are not covered by memorizing nodes on level₀. We have chosen to place a memorizing node at the intersection farthest from the source of two consecutive coverage zones (circles associated with two

memorizing nodes). Placing a memorizing node here makes it possible to cover a greater zone of nodes that are not yet covered, thus minimizing the total number of necessary memorizing nodes to cover the entire zone being studied. This method of construction imposes a condition on the number of nodes that can be placed at level₀ (the number of nodes which will memorize information). Indeed, the distance separating two memorizing nodes needs to be such that the coverage associated with the two nodes has an intersection. This is illustrated by Figure 3.5.

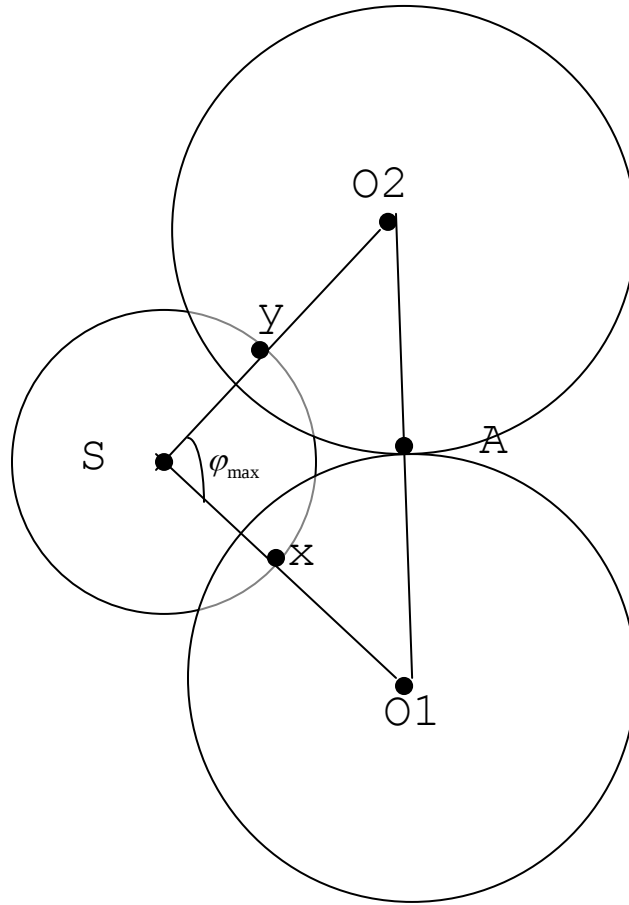


Figure 3.5. Maximum angle able to exist between two nodes so that their circles of coverage have an intersection.

If we note $\varphi_{\max}$ the angle formed by the two nodes, we can determined $\varphi_{\max}$ as follow:

$$\begin{aligned}\cos \frac{\varphi}{2} &= \frac{SA}{SO_1} = \frac{SA}{L} = \frac{\sqrt{L^2 - R^2}}{L} \\ &= \frac{\sqrt{L^2 - \alpha^2 L^2}}{L} = \sqrt{1 - \alpha^2} = (1 - \alpha^2)^{1/2}\end{aligned}$$

$$\begin{aligned}\text{So, } \quad \frac{\varphi}{2} &= \text{ArcCos}(1 - \alpha^2)^{1/2} \\ \varphi &= 2\text{ArcCos}(1 - \alpha^2)^{1/2}\end{aligned}$$

Then,

$$\varphi_{\max} = 2\arccos(1 - \alpha^2)^{1/2} \quad (3.3)$$

Thus we deduct the number of necessary memorizing nodes to cover the entire level₀:

$$\mathbf{n} = \left\lceil \frac{2\pi}{\varphi_{\max}} \right\rceil \quad (3.4)$$

While the number of memorizing nodes within a level is reduced, the more important the distance between two memorizing nodes on this level becomes. This implies that the intersection of circles associated with two consecutive memorizing nodes will be close to the source and thus, the more important the number of levels necessary to cover the entire zone will become.

Conversely, while the number of memorizing nodes on a level is important, the more likely that the intersection of circles associated with two consecutive memorizing nodes will be far from the source and thus, the less important the number of levels necessary to cover the whole zone will be.

Once the number of nodes n is determined, the value of the angle φ (the angle separating two nodes memorizing on the level₀) can be deduced:

$$\varphi = \frac{2\pi}{n} \quad (3.5)$$

Knowing the existing angle between two nodes of the level₀, it is possible to consider the extension of coverage of the nodes of level₀. It is necessary to choose nodes located at the limit of coverage of the nodes on level₀ at a distance l_1 from the source. These nodes will belong to the level₁.

The distance l_1 to the source of new memorizing nodes is determined as follows:

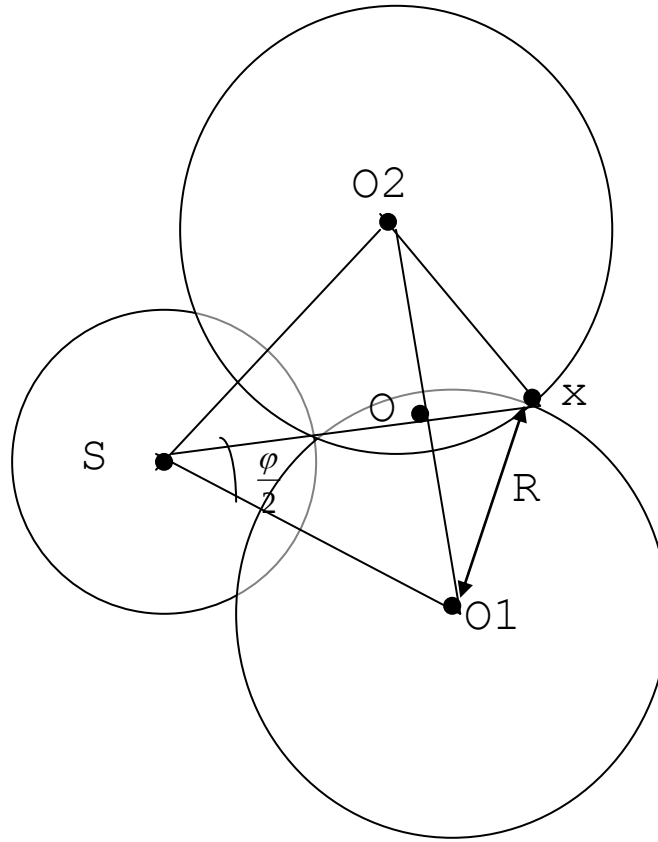


Figure 3.6. Geometrical Representation of Level l_1

$$\begin{aligned}
l_1 &= SO_1 \cos \frac{\varphi}{2} + \alpha x \\
&= L \cos \frac{\varphi}{2} + \alpha x \\
&= L \cos \frac{\varphi}{2} + \sqrt{R^2 - oo_1^2} \\
&= L \cos \frac{\varphi}{2} + \sqrt{R^2 - L^2 (\sin \frac{\varphi}{2})^2} \\
&= L \left(\cos \frac{\varphi}{2} + \sqrt{\alpha^2 - (\sin \frac{\varphi}{2})^2} \right) \\
&= \frac{1}{1 - \alpha^2} l_0 \left(\cos \frac{\varphi}{2} + \sqrt{\alpha^2 - (\sin \frac{\varphi}{2})^2} \right) \\
&= \frac{\cos \frac{\varphi}{2} + \sqrt{\alpha^2 - (\sin \frac{\varphi}{2})^2}}{1 - \alpha^2} l_0
\end{aligned}
\qquad \sin \frac{\varphi}{2} = \frac{oo_1}{L}$$

Then

$$l_1 = \frac{\cos \frac{\varphi}{2} + \sqrt{\alpha^2 - (\sin \frac{\varphi}{2})^2}}{1 - \alpha^2} l_0 \quad (3.6)$$

φ represents, as was previously the case, the angle separating two nodes having consecutively memorized information.

The level $n+1$ is given by considering the most distant intersections from the source of the circles associated with the consecutive nodes having memorized in level n . so, to generalize we can determined the level l_n . For that l_n can be determined in the following way:

$$l_n = \left(\frac{\cos \frac{\varphi}{2} + \sqrt{\alpha^2 - \left(\sin \frac{\varphi}{2} \right)^2}}{1 - \alpha^2} \right)^n l_0 \quad (3.7)$$

4. Distribution Algorithm

Information distribution is brought about by the diffusion of a package containing some data about information requiring distribution. Only the nodes belonging to a particular level will have the possibility of being an information source. Also, because of mobility, those nodes are not always the same nodes functioning as the information sources. By applying our idea it is possible to obtain two same-level nodes that are so close to one another as to have the same distribution information. One of these nodes would then be redundant since only one of them can do the work. Thus, the redundant number of nodes that will be information sources can be reduced by choosing them separated by a distance d which can be determined as follows:

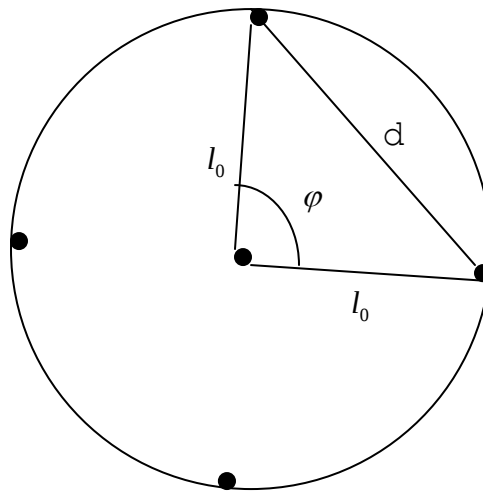


Figure 3.7. Constructing Distance d

$$\begin{aligned}
d^2 &= l_0^2 + l_0^2 - 2l_0^2 \cos \varphi \\
&= 2l_0^2 - 2l_0^2 \cos \varphi \\
&= 2l_0^2 (1 - \cos \varphi) \\
d &= l_0 \sqrt{2} \sqrt{1 - \cos \varphi} \tag{3.8}
\end{aligned}$$

In the case where two nodes separated by this distance cannot be obtained, we choose the node which is located with the maximum distance from the source x less than d .

The algorithm to be executed on each node is given by Figure 3.8.

```

For all the nodes  $x \in G(V, E)$ 
    R: =  $l_0$ 
    For  $i = 0 \rightarrow i = n$  do
         $d = l_0 \sqrt{2} \sqrt{1 - \cos \varphi}$ 
        if  $d(S, x) = l_i$  save information in node  $x$ 
        node-set =  $\Phi$ 
        for all nodes  $y$  s.t  $d(S, y) = l_i$ 
            node-set.add( $y$ )
            loop:
                node-set.remove( $x$ )
                find  $y_j$  s.t  $d(x, y_j)$  is maximal  $\leq d$  and  $y_j$  has only
                    one memorize node w/in  $d$ 
                if  $y_j$  does not exist
                    save information to node w/in maximal dist  $\leq d$ 
                    break
                save information in the node  $y_j$ 
                 $x \leftarrow y_j$ 
            End loop
        End for
    End For
End For

```

Figure 3.8. Distribution Algorithm

E. CHAPTER SUMMARY

An overview of the previous work such as discovered services, geometrical routing and co-operative caching techniques were presented. Then an information distribution specification was developed using a mathematical model. In

addition, some geometrical formulas were used while developing the mathematical model proving the author's equation results.

The next chapter presents the statistical results obtained from different case studies carried out and provides detailed statistical analysis of the results.

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IV. SIMULATION RESULTS

A. OVERVIEW

This chapter presents the statistical results generated from different cases, and provides a detailed analysis (of the statistical results), to determine the contributing factors for information distribution in an ad-hoc network. This chapter will focus on the following key points: Performance evaluation, influence of the parameter α that controls the maximum distance separating a node that has information from a node that does not, and the effectiveness of the algorithm.

B. RESULTS AND ANALYSIS

For the simulations, OMNETPP [58] is used. The simulated network utilizes an MF 802.11 conform MAC protocol. In all simulations the nodes move on an 800m×800m square area using the random mobility model. Each host is initially placed at a random position within the simulation area. As the simulation progresses, each host pauses at its current location for a period, called the pause time, and then randomly chooses a new location to move to. Each host continues this behavior, alternately pausing and moving to a new location, for the duration of the simulation. Thus, the nodes move according to steady-state distribution for the random Waypoint Mobility Model with the speed set to truncnormal (20, 8). A transmission range of 100m is assumed. The study also examines some scenarios with different numbers of nodes (50, 100, 150, 200, 250, 300),

different values of α (.3, .4, .45, .6, .7, .8, .9), and different distributions (uniformly, truncnormal, normal) to observe the impact of these parameters on distribution.

These simulation details are summarized in Table 4.1. The algorithm is run based on input parameters to examine some scenarios to test its effectiveness. Derived parameters are calculated from the input parameters. The node density is simply calculated by dividing the number of nodes by the simulation area size. The coverage area is determined by the area of the circle with a radius equal to one node's transmission range. A node's transmission footprint is the percentage of the simulation area size covered by a node's coverage area. The maximum path length is the length of a diagonal of the simulation area size. The network diameter is the maximum path length divided by a node's transmission range. The network connectivity is based on the average number of neighbors.

The value identified as "no edge effect" is calculated by dividing the coverage area by the node density. Considering the fact that nodes near the edges do not have neighbors on all sides of the node yields the value labeled "edge effect."

Input Parameters	
Number of nodes	50, 100, 150, 200, 250, 300
Simulation area size	800m X 800m
Transmission Range	100m
Average Simulation Duration	300s
Derived Parameters	
Node density	1N/12,800m ² , 1N/6,400m ² , 1N/4,266m ² , 1N/3,200m ² , 1N/2,560m ² , 1N/2,133m ²
Coverage area	31,416m ²
Transmission Footprint	4.91%
Maximum Path Length	1131.37m
Network Diameter	11.31
Mobility Model	
Mobility Type	Mass Mobility
Mobility Change interval	truncnormal(2, 0.5)
Mobility Change Angel By	Normal(0, 30)
Mobility Speed	truncnormal(20, 8)
Mobility update Interval	0.1
Simulator	
Network	Net80211
Simulator used	MF802.11 (OMNETPP)
Medium Access Protocol	IEEE 802.11
Carrier Frequency	2.4e+9
Power Max	2.0 mW
Channel Control Number	1
Bit Rate	2 Mbps

Table 4.1. Simulation details

In these simulations, performance was measured in terms of the number of nodes as an information source. The simulations also attempt to minimize the number of nodes that could serve as an information source and cover the entire zone studied. The zone considered to be covered is the totality of the network.

1. Performance Evaluation

By evaluating the number of nodes located within a distance " l " from the source in comparison to the total number of nodes and varying the parameter α it is possible to come up with a certain precision of those nodes as given by the following Figure 4.1.

The number of nodes within a distance " l " is shown in ordinate and the total number of nodes on the abscissa. Therefore the precise number of nodes with information increases according to the number of nodes in the zone requiring coverage. It means that when the density of the network is important precision approaches 1 (perfect case).

	l_0	l_1	l_2	l_3	l_4
.3	100	115.935	134.358	155.739	180.521
.4	100	121.030	146.482	177.286	214.568
.45	100	123.307	152.047	187.486	231.184
.6	100	128.847	166.016	213.907	275.613
..7	100	195.081	380.568	-	-
.8	100	219.901	-	-	-
.9	100	219.421	-	-	-

l_5	l_6	l_7	l_8	l_9
209.247	242.545	281.141	325.879	377.736
259.691	314.304	380.400	–	–
285.067	351.509	–	–	–
355.120	–	–	–	–
–	–	–	–	–
–	–	–	–	–
–	–	–	–	–

Table 4.2. Levels toward Parameter α

In Table 4.2 it is possible to see that to cover the entire zone a certain number of levels ($l_0, l_1, l_2, \dots$) are required and that this is strongly dependent on the value of the parameter α . For instance, when α is small let say ($\alpha = .3$) at least 10 levels are needed to cover the entire zone, but by continually increasing the parameter α the number of levels clearly decreases; and becomes only two levels to cover the entire zone for the case where the parameter ($\alpha=.8$) as shown in Table 4.2.

Now let us examine the case of $\alpha = .8$.

For $\alpha = .8$ and according to Table 4.1 two levels (l_0 and l_1) are needed to cover the entire zone. For each level, the theoretical number of nodes that memorize information is 6 nodes (this is calculated experimentally according to the mathematical model presented in Chapter III). Thus, to cover the entire zone, theoretically 12 nodes are needed that have the information to be distributed [theoretical ideal is 1 (12/12)].

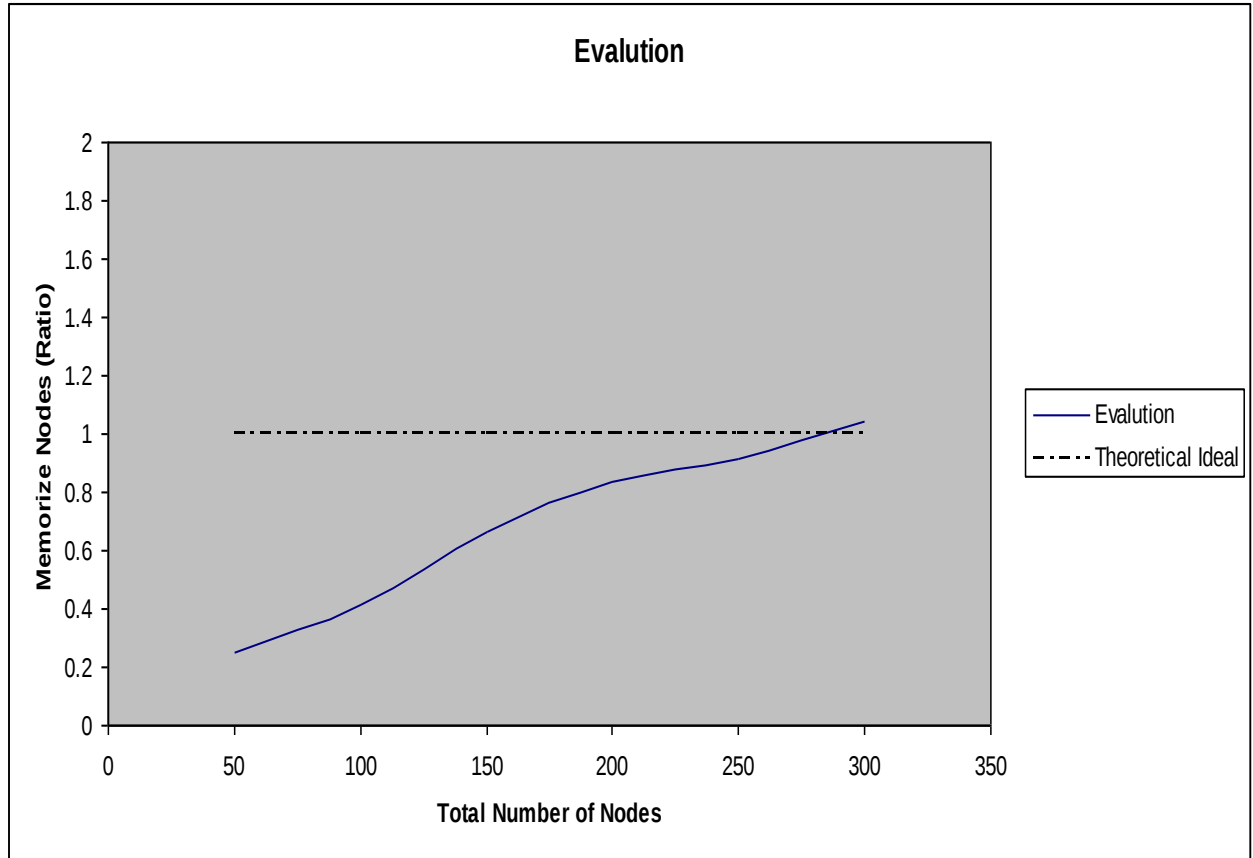


Figure 4.1. Evaluation of the Memorizing Nodes in Comparison to Total Number of Nodes

2. Influence of the Parameter α

The parameter α plays an important role in this work and has a great influence on the number of nodes that are required to be an information source. Figure 4.2 shows the proportion of nodes that memorize information toward the total number of nodes based on the parameter α . Thus, according to these results it is obvious that the influence of the parameter α is not the only the factor that influences the number of nodes that will have information to serve as an information source, but also that the density of

the network plays an important role in this case. As the parameter α increases, the number of nodes that memorize information decreases, and vice versa.

For the case where the number of nodes is 100 in the 800m*800m zone, the density is light; the distribution of those nodes also influences the phenomena. For this reason, the influence of the parameter is not particularly important. Neither is the number of memorizing nodes significant, which is shown in Figure 4.2. However, by continually increasing the total number of nodes in the network, the influence of the parameter becomes more and more significant.

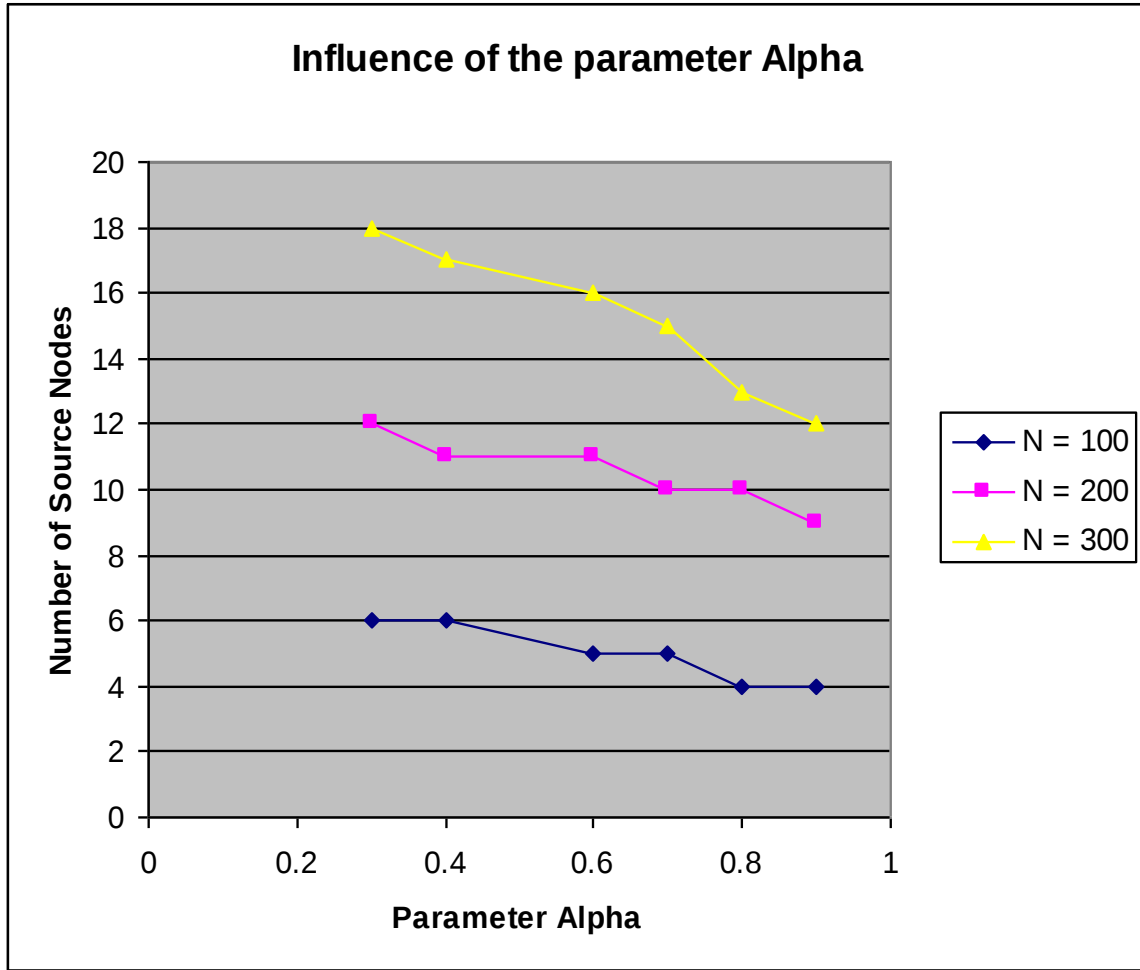


Figure 4.2. Influence of the Parameter Alpha

3. Effectiveness of the Distribution Algorithm

This section will show the effectiveness of our algorithm by examining some cases which are similar to a real case. This simulation examined some scenarios with a fixed number of nodes (300 nodes), different values of α (.4, .6, .8, .9), and different distances from the source (100, 150, 200, 250, 300, 350, 400).

The results obtained are very logical when comparing them to a real case. By constantly moving away from the

source, the number of nodes that will be an information source decreases towards a theoretical number. It is also possible to see that the closest case to a real case is for the parameter $\alpha = .9$. This is normal because of the influence of this parameter, as mentioned in the previous sections (when the parameter α increases, the number of nodes that memorize information decreases). According to the results shown in Figure 4.3 it is possible to see that the algorithm is very efficient in the case of large number of nodes. However, it always responds to the study's goal for a small number of nodes by minimizing the number of nodes that will have information to be an information source.

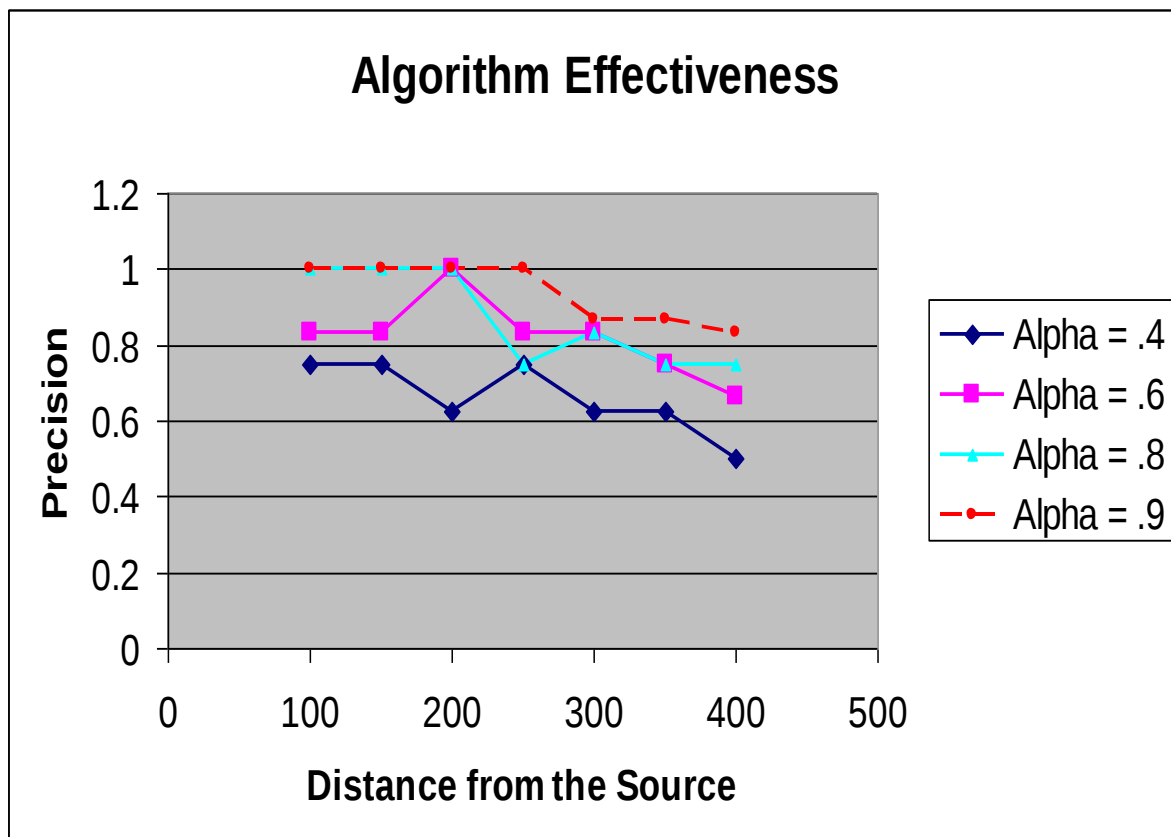


Figure 4.3. Algorithm Effectiveness

The following scenario was constructed to demonstrate how the source nodes are distributed in the entire zone and what these nodes in this example of simulation are. The number of nodes is 200 and the parameter α is set to 0.7; several iterations of the application were run. Figure 4.4 below, reflect the respective results.

Figure 4.4 shows how the nodes that memorize information function as an information source to cover the entire zone. In this case scenario the entire nodes are blue while the green ones represent the information source that will cover the studied zone.

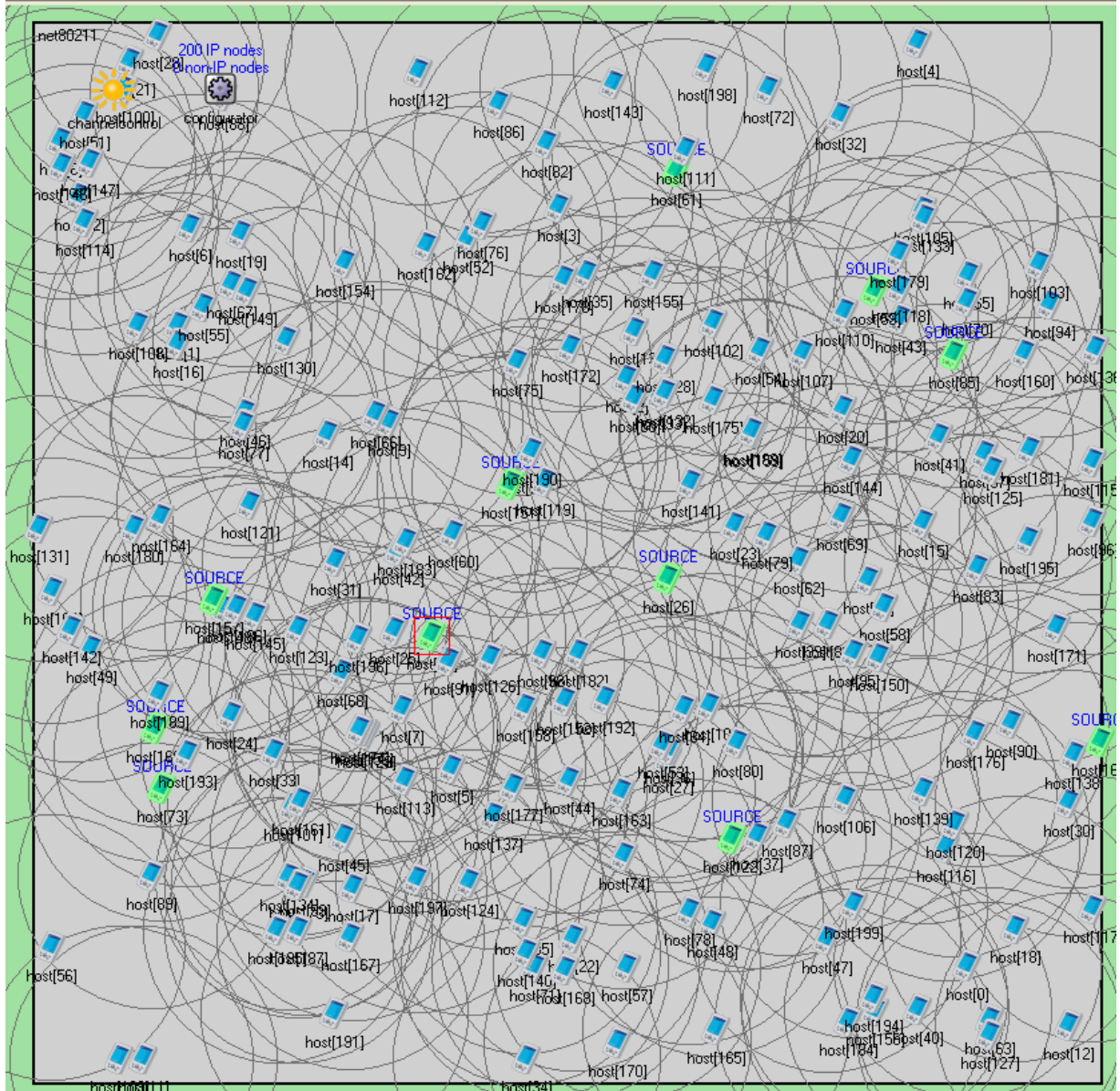


Figure 4.4. Screenshot of Information Distribution for the Scenario ($N = 200$, $\alpha = 0.7$)

C. CHAPTER SUMMARY

This chapter has presented statistical results derived from the data collected. A detailed analysis of the results was conducted and discussed. The results pointed out some of the attributes in each of the identified key components of

information distribution which affected the information source. The chapter also showed that information distribution is influenced by two principal parameters: parameter α and network density. When, parameter α increases, the number of information source decreases, and vice versa. Also, network density influences the number of information sources.

The following chapter summarizes and concludes the thesis research. It discusses research areas that have not been explored due to a lack of time and resources, and provides recommendation for further research in related areas.

V. CONCLUSIONS AND FUTURE WORK

A. OVERVIEW

This chapter presents the main conclusions derived from the different levels of performance and efficiency of the algorithm. Also, some additional work for the thesis study is proposed.

B. CONCLUSIONS

Wireless technology has the potential to significantly simplify the deployment of data networks. While significant progress has been made in recent years, for the most part, this potential has not been fully realized. Ad-hoc networks can accomplish this; they are easy to deploy for the simple reason that they do not require infrastructure and configure themselves automatically.

This thesis presents a solution to some important problems in the management of service in ad-hoc networks. The study is limited as regards the material to be sent on the network nodes constituting the network. Thus, it was necessary to develop an algorithm which requires only information on the local vicinity, because this is easy to obtain. This work's algorithm starts by picking a random node (e.g., "S") that has the information to be distributed. The communication range l_0 represents the minimal distance from which distributed information is examined. The nodes located inside the circle with center S and radius l_0 : $\zeta(S, l_0)$ are covered by S and get information from S . The

nodes located on the circle with center S and radius l_0 are at the limits of coverage. These nodes are on level l_0 , within a distance l_0 from the source. Some of these nodes will have to memorize information and thus it will be possible to extend coverage beyond level l_0 . These nodes will provide coverage up to a certain distance from the source, which is controlled by the parameter α (defined in Chapter III). To avoid the case that two or more nodes located very close to each other on $\zeta(S, l_0)$ both memorize information, the algorithm addresses this problem by separating two memorizing nodes by a distance d (defined in Chapter III). Those memorizing nodes will extend the coverage zone level l_0 . It is then necessary to choose nodes located at the coverage limits for the nodes on level l_0 at a distance l_1 (defined in Chapter III) from the source, in order to minimize the information source. These nodes will belong to level l_1 and so on, until the entire zone is covered.

Because it does not use an algorithm requiring complete knowledge of the network, and because of the completely distributed character, this study's methods are fault-tolerant and able to function for networks of large size and high density. In order to accomplish this, the study proposed an effective method of information distribution in the network.

First, a criterion was proposed that allows judging the efficiency of information distribution in the network. This criterion deals with the control of the maximal distance that separates a node that has information from one that is seeking that information in order to reduce the cost of the distribution, as well as cost of research.

Second, based on this criterion, a distributed algorithm was implemented that permits information distribution in an ad-hoc network.

Simulation work shows that this algorithm works successfully for both small networks and large networks. This depends strongly on the parameter α and the density of the network. As this parameter increases, the number of nodes which memorize information decreases, and vice versa. Also, simulation work shows that for large value of α (0.9) and some network densities one approaches the theoretical case.

C. FUTURE WORK

The author's work offers several possibilities for future work. First, with regard to its improvement, indeed, although this study's protocol is effective, it is possible to further improve its results.

Regarding distribution, it appears important to take into consideration the capacities of each node. The criteria that should be taken into consideration are energy supply, the cache and its size, and the stability of the node. By stability, stability of the vicinity is understood. Indeed, a node whose vicinity changes less frequently could be a good candidate to be an information source.

This study's general approach to information distribution is usable not only in the search for services, but also in any application requiring fast access to data (such as file sharing, required position, etc.).

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