Content-based Query Support in Ad Hoc Wireless Networks using Information-Fading and Narrow-Casting for Efficient Resource Handling in Disaster Management

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Abstract— **This paper presents a novel *content-based* query support for handling resources in fully distributed ad hoc wireless networks in the context of Disaster Management (DM). In a typical DM scenario, the most common problem is the inefficient management of resources *(like food, drinking water, medicine etc.)* due to poor co-ordination and lack of communication among the heterogeneous groups participating in relief operations. A proper approach thus, needs to be adopted for efficient management of relief operations. This should be capable of assimilating the information regarding inventory of resources from different participating groups and disseminate it over the distributed network in a fully decentralized manner. The major contribution of this paper is a two-layered approach of *content-based* searching using *narrow-casting* superimposed over a broadcasted *information-fading* layer. The objective of *information-fading* is to make a node aware of information content of other nodes in the network through broadcast-based multi-hop percolation of information. However the preciseness of knowledge about a node decreases or fades away with hop-distance, thus reducing the information overhead. The term *fading* of information actually implies propagation of progressively summarized information based on a semantic classification of information. In such a *knowledge-network*, our *content-based* query retrieval process becomes quite effective and uses *narrow-casting* (as opposed to broadcasting) to access the prospective destination through the relevant set of nodes only. Thus we have developed an intelligent multi-hop information retrieval system where the query itself will lead the search process to get the proper information from the nearest available destination. The per-hop narrowing of the search space will eventually reduce the unnecessary visits to irrelevant nodes. We present results from detailed simulation, showing remarkable reduction in the search domain by 2.5 times. We have also discussed the scalability of this model to larger networks.**

Index Terms — **Ad hoc Networks, Content-Based Query, Disaster Management, Information-Fading, Narrow-Casting.**

I. INTRODUCTION

Natural and man-made disasters such as earthquakes, floods, storms, structural collapses, etc., pose an ever-present challenge to public emergency services. In order to cope with such disasters in a fast and highly coordinated manner, the optimal provision of information concerning the situation is an essential pre-requisite. However in the hours and even days following these events communication is often limited because existing infrastructure was destroyed or the event occurred in an area without infrastructure. Thus, there arises a recognized need for rapidly deployable wireless communications, including wireless ad hoc networks that can be formed among the relief workers carrying handheld devices or laptops for emergency management [1-4].

However the formation of a wireless communication infrastructure alone does not ensure efficient and effective Disaster Management (DM). In a typical DM scenario, the most common problem is the inefficient management of resources *(basic commodities like food, drinking water, medicine etc.)* due to poor co-ordination and lack of communication among the heterogeneous groups participating in relief operations. In fact, the nature of necessity and degree of devastation may vary even within the affected area thus, the relief requirement cannot be analyzed *a priori*. As a result, the initial relief is distributed in random manner with a follow up of urgent demands. This clearly indicates that a proper approach needs to be adopted for efficient management of relief operations that should be capable of assimilating the information regarding inventory of resources from different participating groups and disseminate it over the distributed network in a fully decentralized manner [4].

Our work underlines the need and importance for the content-based searching as well as routing in the context of a fully distributed *Decentralised Disaster Management Information Network (DDMIN)* [4]. For example, let us assume that a relief worker urgently requires some amount of cholera vaccine. In such cases, there is a high need of getting right things in right amount at right time from a right place i.e. a place that is physically near and accessible in such an emergency situation. In a distributed network with only wireless connectivity and no centralized control, these kinds of random searches *(the node issuing the query have no prior idea about the location of the destination)* can only be handled using *content-based* routing schemes [5, 8].

A ***content-based*** network can be thought of as a dynamically configurable broadcast network where each message is treated as a broadcast message and the broadcast tree is dynamically pruned using content-based addresses. This kind of exhaustive search for a suitable destination *(whose interest matches with the content of the message)* may eventually flood the network as the broadcast tree expands with the expansion of the network.

The major contribution of the paper is a two-layered approach of content-based routing using "*Narrow-Casting*" superimposed over a broadcasted "*Information-Fading*" layer, which provides an efficient distributed query support system thereby reducing the control overhead subsequently to a large extent. The objective of ***information-fading*** is to make a node aware of the information content of other nodes in the network through broadcast-based multi hop percolation of information. The preciseness of knowledge about a node decreases *(or fades away)* with hop-distance, thus reducing the information overhead. The term "fading" of information actually implies propagation of 'progressively summarized information' based on a semantic classification of information. For example, let us assume that a node X having vaccines of different types contains the *detailed inventory of those vaccines*. The one-hop neighbors of X will be aware that node X contains *different types of vaccines (by knowing their names only)* but don't know about the inventory of those vaccines. The two-hop neighbors of X will be aware that node X has *vaccines* but don't know about the type of vaccines at X. The three-hop neighbors of X would know that node X is having some *preventive drugs* as opposed to *curative drugs*. The four-hop neighbors of X would know that X contains *drugs*. The nodes five-hop away from X or more will be at a "don't know" state about node X. This hierarchical structure based on semantic fading of "DRUG" is illustrated in figure 1.

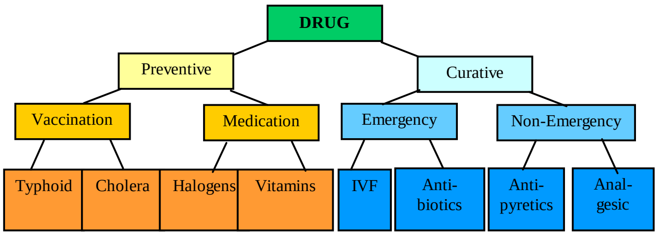


Fig. 1 Semantic Based hierarchical classification on DRUG

Thus, the Information present at a node is broadly classified into several semantic hierarchical subgroups (for example, Figure 1) and is forwarded to its neighbors. Each neighbor in turn will further reduce the received content following the more abstract level semantic categorization. As a result, the level of abstraction of content gets increased at each hop as if fading the meta-information like a ripple in a pond.

The term ***narrow-casting*** means the prospective recipients of a message can be selected from all the available audience pool. Our content-based narrow-casting layer limits the flow of each search message to only those nodes that have faded information matching the message.

In a traditional content-based network each node advertises a predicate i.e., the messages that the node intends to receive. The content-based service consists of delivering messages to the intended receiver through extensive broadcast until the intended destination is found. Compared to that, our proposed ***knowledge-based*** architecture uses progressively faded information to limit the flow of search message among the nodes that have at least some information relevant to that query. This not only minimizes the traffic but also optimally guides the search towards intended destination avoiding unnecessary traversal of the search message around the network.

The paper is organized as follows. In the next section, some of the related works are illustrated. Proposed content-based searching scheme that relies on information-fading and narrow-casting is discussed in details in sections 3 and 4. The proposed scheme is evaluated through simulation and the results are discussed in section 5. Section 6 concludes the paper.

II. RELATED WORK

Contemporary researchers have proposed several content-based search techniques for distributed ad hoc networks [5-8]. Some of these approaches are used to share files by providing search capability based on file–name match and possibly content type. What all these applications have in common is the flow of information from source to destination that is determined by the specific interests of the receivers [5,6]. With this communication pattern, receivers subscribe to information that is of interest to them without regard to any specific source while senders simply publish information without addressing it to any specific destination. This type of content-based searching yields better result when a particular group of common interest can be identified dynamically in the network. In a disaster management (DM) scenario where the queries are random in nature and that too generated on a real time basis, this kind of publish-subscribe or push-pull method may generate message flooding in the network.

In contrast to the existing approach of content–based network (CBN) our approach proposes a semantically hierarchical structuring based information flow in a faded manner from each node of the network to the surrounding region. Instead of multicasting to a specific interest group narrowcasting using faded information could be characterized by searching only a narrow set of nodes having relevant information. Some example protocols on content-based routing [7, 8] have attempted to construct and maintain multicast trees despite topology changes, but in all the above mentioned models the receivers know about the sender's identity, but not vice versa. The typical problems of content-based network lies in the use of correlated attributes/ predicates, thereby posing a huge challenge to modern query optimizers. Given a distributed environment having huge decentralized data it would become quite expensive to track correlation in large, update-intensive databases [9]. Our information-fading based approach helps us to implement an intelligent multi-hop information retrieval system where the query itself will lead the search process to get the proper information from the nearest available destination. The per-hop narrowing of the search space will eventually reduce the unnecessary visit of irrelevant nodes.

III. INFORMATION-FADING

The commonly used relief materials for disaster management (DM) can be classified into some fixed categories [4] and they are the resources to be managed during a typical disaster. Each resource can be further classified in an organized tree structure through different levels of semantic abstraction, agreeable to all the participating hosts. For example, let us assume that the relief materials are broadly classified under headings like “FOOD”, “DRUG”, “WATER & SANITATION” etc. The broad class say “DRUG” has been further categorized, as shown in figure 1. Similarly other trees can be formed under roots “FOOD”, etc. The necessity of information grouping under a common semantic head (as shown in figure 1) is advantageous when a node is having multiple and heterogeneous items of same category. In that context, only category name is sufficient to serve the purpose of information fading. As the information structuring is generally static in nature, each node will maintain these information trees related to relief materials.

An example network in Fig 2 may be taken where node A may have, for example, an initial stock of Vitamins and will maintain an inventory on that, and another node G may have a stock of Antibiotics . Both the nodes will issue periodic beacons indicating their content with one-level fading to their neighbors using the semantic tree on DRUGS for fading purpose. So, in this way neighbors of A will know that A is having general “Medication” type drugs and neighbors of the neighbors of A will know that A is having some "Preventive" drugs. Similarly, neighbors of G will know that G is having "Emergency” drug and two hop neighbors of G will know that G is having “Curative” drugs. Thus the information is getting faded at each hop and gradually gets spread across the surrounding region of a node and the region may be limited by hop count. Based on these exchanges of resource information, each node will form a faded resource information table (as shown in figure 3). Each row in such table contains the faded resource information received from other nodes and the suitable next hops to access the corresponding nodes in the network. Thus a table essentially contains three fields; the first one is node-id (say N) whose resource information is available in that row and the second field contains the information received from N. The last field contains next hop node-id (say M) through which N can be tracked. The table plays a dual role of information surfing as well as topology informer and in this way each node acts as an autonomous router. As the range of spreading can be adjusted using hop counts, nodes, far away from a particular node A, are assumed to be in a “don’t know” state about resources available at A. This limits the spreading of all the messages throughout the entire network. Moreover, due to the semantic structuring of data, the size of messages that is flowing through the network including the amount of information that needs to be stored at each node is remarkably small. The table at each node (figure 3), provides an in-depth view about the immediate neighbors and an overview of the information present at distant nodes. This table gets updated periodically as and when the stock of a particular item gets exhausted or added. This updated information percolates through the network periodically. Thus our faded-information-network contains enough knowledge to realize an intelligent multi-hop information retrieval system which will be discussed subsequently.

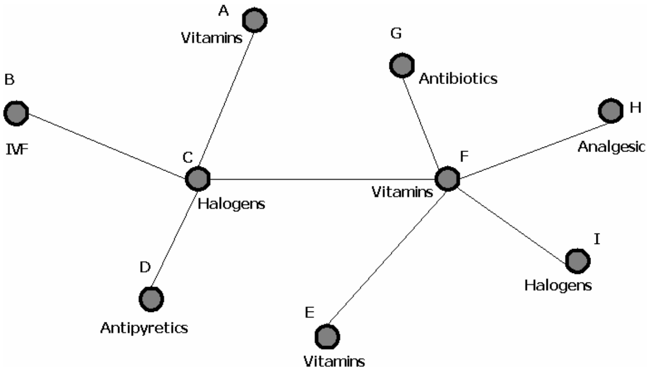
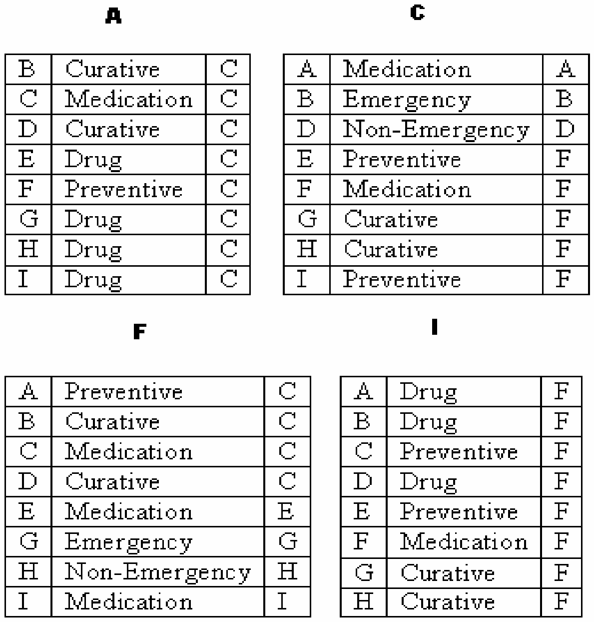


Fig. 2 A Network showing available resources at each node



A

B	Curative	C
C	Medication	C
D	Curative	C
E	Drug	C
F	Preventive	C
G	Drug	C
H	Drug	C
I	Drug	C

C

A	Medication	A
B	Emergency	B
D	Non-Emergency	D
E	Preventive	F
F	Medication	F
G	Curative	F
H	Curative	F
I	Preventive	F

F

A	Preventive	C
B	Curative	C
C	Medication	C
D	Curative	C
E	Medication	E
G	Emergency	G
H	Non-Emergency	H
I	Medication	I

I

A	Drug	F
B	Drug	F
C	Preventive	F
D	Drug	F
E	Preventive	F
F	Medication	F
G	Curative	F
H	Curative	F

Fig.3. Faded Information Table maintained at different Nodes
(for example, tables at A, C, F and I are shown)

IV. QUERY SUPPORT USING NARROW-CASTING

Let us take an example network as shown in figure 2 and the faded information table at A, C, F, I are shown in the figure 3. Let us assume that node I generates a query "Search for IVF". Node I will search for immediate parent of `<IVF>` i.e., `<Emergency>` in its information table. No row containing `<Emergency>` is found in its table, so, node I will search for other higher level predecessors of `<IVF>` i.e., `<Curative>`. Table at node I shows that `<Curative>` drugs are available at G and H. So, node I will narrowcast the query to the corresponding next hops of those two rows, which is happened to be same (F) in this case. Then I will wait for the *Narrowcast_Timeout* to get feedback from F. Now, F, on receiving the query "Search for IVF", will repeat the search for parent of `<IVF>` i.e, `<Emergency>`. Table at F shows that G contains `<Emergency>` so, F will unicast the search to G and wait for the reply until *Unicast_Timeout*. But, G will eventually send a negative reply to F and F will reinitiate the search for grandparent of `<IVF>` i.e, `<Curative>`. `<Curative>` is found at Node B and D in the information table maintained at F and to reach there next hop is C. So, F will issue a narrowcast search query for `<IVF>` to C and will wait for *Narrowcast_Timeout*. C in turn will execute the search in the same process and will find that the parent of `<IVF>` i.e., `<Emergency>` is available at B. C will then unicast the query to B and will wait for *Unicast_Timeout*. B sends back the positive reply to C with the available quantity of `<IVF>` and C will piggyback this result to F and the result will finally reach to I. This way, depending on the precision of available information a node will perform the initial search using unicasting or narrowcasting or a combination of both which will eventually lead the query towards prospective destination. If that fails, then the node will go for broadcasting. The timeout periods for narrowcasting, selected by a node, depends on the degree of precision of the relevant information available to that node. If the precision is high i.e., the node has the knowledge about the immediate parent of the desired query string, then timeout should be small. Timeout period will increase with the decrease in the precision of available information related to the search string.

The following algorithm illustrates the steps to be followed for executing a search query from a node as for example, "I" generates a query "Search for IVF":

```
Step I: Consult the Drug tree and Find immediate parent of <IVF> (i.e., "Emergency" as per figure 1)

Step II: Search its own Faded Information table for <Emergency>
  If <Emergency> is found in some rows
  /*Meaning that the corresponding next hop is having some emergency medicines, like <IVF> or <Antibiotics> or both */
  {
    Unicast to the corresponding Next hop for <IVF> and wait for Unicast_Reply until Unicast_Timeout

    If Unicast_Reply = FALSE
      /*Corresponding next hops have some emergency medicine other than IVF*/
    {
      /*Reinitiate Search for the rows containing any member belonging to the sub-tree routed to leaf <IVF> i.e., search for rows containing <Curative> or <Drug>*/

      Step III If any row containing <Curative>/<Drug> are found
      {
        Narrowcast to the corresponding Next hop for <IVF> and wait for Narrowcast_Reply until Narrowcast_Timeout

        If Narrowcast_Reply = FALSE
        /* The neighbors have some <Curative> medicine other than <IVF>*/
        {
          Reinitiate Search with broadcast for <IVF>
        }
        Else if Narrowcast_Reply = TRUE
        {
          Repeat search algorithm (Go to step I) at corresponding next hops
        }
      } /*End of Narrowcast*/
      Else
        /* If rows containing <Curative> or <Drug> are not found */
      {
        Reinitiate Search with broadcast for <IVF>
      }
    }
    Else
    /* If Unicast_Reply = TRUE i.e., Next hop has <IVF>*/
    "RESULT IS FOUND" at corresponding Next hop
  }
  Else
  /* <Emergency>not found; Reinitiate search with parent of <Emergency> and so on*/
  Go to Step III
```

V. PERFORMANCE EVALUATION

In this section we present the simulation results and study the nature of message reduction in the network using narrow-casting. We have taken 30 randomly distributed mobile nodes over the network. The distribution of data files among the nodes was also made in a randomized manner. We have invoked searches from widely varied sources to evaluate the result independent of the topology. To observe the behavior of narrowcasting over broadcasting, the searches are made where the result lies within one hop, two hops and readings have been taken up to five hop. Different set of readings have been taken and averaged.

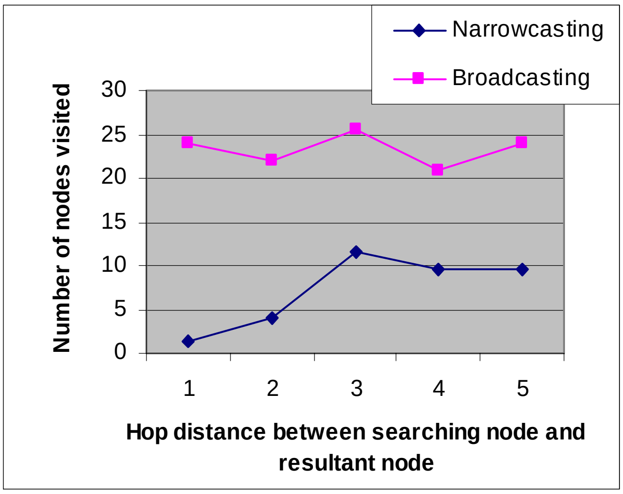


Fig.4. Performance analysis showing the advantage of Narrowcasting over Broadcasting with increasing hop distance.

Figure 4 clearly indicates the fact that the spread of search message in the network using broadcasting is always much higher than using narrow-casting irrespective of topology. This is the outcome of the fact that when the resultant destination lies multi-hop away, the number of irrelevant node-visit increases with simple broadcast search. Thus it can be concluded that the search-space with broadcast is 2.5 times more than that with narrow-casting, if we use network with nodes containing faded information about other nodes or *knowledge-network*. In such a knowledge-network, our content-based query retrieval process becomes quite focused and uses narrowcasting *(as opposed to broadcasting)* to access the relevant set of nodes only.

VI. CONCLUSION

In this paper we have developed an intelligent multi-hop information retrieval system where the query itself will lead the search process to get the proper information from the nearest available destination. The per-hop narrowing of the search space will eventually reduce the unnecessary visit of irrelevant nodes. The benefit of narrowcasting with information fading will be more pronounced in large network handling frequent queries.

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