SENCAST:
A Scalable Protocol for Unicasting and Multicasting in a Large Ad hoc Emergency Network

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Summary

This paper presents a novel protocol, SENCAST, *a scalable protocol for large ad hoc emergency network for unicasting and multicasting.* SENCAST is scalable to a very large ad hoc network and adheres to emerging communication scenarios in emergency systems where mobile nodes typically work as a group and are involved in a collaborative manner. SENCAST not only distributes real-time information efficiently in such an environment, but the paths are discovered with low overheads by limiting the scope of route discovery packets to a region of potential paths creation.

SENCAST uses context information like bandwidth available and location. Route reconfigurations are localised and thus limiting the sending of control packets to a specific region. The resiliency of the SENCAST is improved with multiple routes. Moreover, based on the movement of the source or the destination, routes may be extended in a localised manner or new routes being discovered in other areas while stale ones are dropped using a soft state approach. Furthermore, despite sending to groups of receivers, SENCAST has no overhead associated with group management.

Key words:

Ad hoc network, routing protocol, multicasting, emergency system, scalability

1. Introduction

Ad hoc networks are usually established by transitory devices, to share resources or for communication purposes, where a pre-existing infrastructure for setting up or connecting to a network may be non-existent. Despite the heterogeneous environment, nodes, being self-administered and self-configured, make use of standard discovery protocols to provide/access services to/from other nodes. This ad hoc mode of communication is also easily and rapidly deployed. As a consequence, this has given rise to a whole new set of applications ranging from small scale and static, for example a set of devices in a patient room interacting with a doctor's PDA, to a large scale and highly dynamic network, like an emergency rescue on a disaster site.

The unpredictability of certain events makes it difficult to have all the 'just-in-time' logistics for the smooth running of emergency operations. However, if a large ad hoc network is present in times of emergency operations, the protocol should not only scale well but also support all possible emerging communication scenarios. Therefore, to meet all the emerging communication possibilities, the protocol must efficiently support unicasting and multicasting. Moreover, the setting up of the communication route may also be based on location, as the disaster site is usually known.

The appropriate protocol should disseminate information efficiently to the receiver(s) using the appropriate context information available. Also due to the multi-disciplinary deployed workforce, the number of nodes in the network may be very high. So, the protocol used must scale up well as the network grows. Moreover, efficient coordination among the different teams and among team members is primordial for carrying out operations on the emergency site. It is therefore imperative that the establishment and maintenance of routes and the complex group management for multicasting is done with a strict limitation on the overheads incurred. Furthermore, high resiliency and a guaranteed QoS level are the key requirements for audiovisual communications.

Numerous multicasting protocols exist as the issues and challenges [1, 2, 3, 4] associated with multicasting in Mobile Ad Hoc Network (MANET) are many. Their desirable properties have been identified in [5, 6, 7] and a comparison of common existing multicasting protocols against the main desirable properties of multicasting protocols, is shown in the Table 1, partly been achieved in [8, 1, 7, 9].

This research paper presents a novel protocol, SENCAST, which will efficiently distribute real-time information on a large ad hoc network for emergency system. Sections 2 give an overview of what has been achieved in this domain. Section 3 presents SENCAST, the proposed protocol to support emergency operations. An application scenario of SENCAST is highlighted in Section 4 and this is followed by a simulation study, Section 5. Then Section 6 gives a summary of observations. Section 7 and 8 highlights the protocol optimizations and concludes this research work respectively.

2. Related work

2.1 Emergency System and Ad Hoc Network

Efficient communication is the basis for the smooth running of emergency operations and can at the same time mitigate the stressing environment of rescue or law enforcement. The two modes of wireless communication that can be used are: (1) *infrastructure-dependent*, and (2) *infrastructure-independent* (ad-hoc) network, which seems to be more promising for contingency planning.

The types of communication involved in an emergency system can be (1) *intra-organisational*, (2) *multi-jurisdictional*, and (3) *multi-disciplinary* [10]. For the mitigation of emergency operations there are three essential aspects described in [11] which are (1) *'just-in-time' logistics*, where the resources are available on the emergency scene instead of having each responder to look for the required equipment stockpiled somewhere, (2) *situational awareness*, where responders should be warned of possible menacing threats at earliest to minimise risks, and (3) *enhanced situational awareness*, which address issues such as coordination of operations by multiple agencies.

The call for emergency preparedness leaves ad hoc networks as an attractive tool for communication support mainly because of its ease of deployment, infrastructure-less and highly dynamic topology. This has incited projects like WIDENS [12] (Advanced Wireless Deployable Network System for Public Safety), a European project, and DAWN [13] (Dublin Ad Hoc Wireless Network) project, aim at covering the whole city of Dublin, among others.

Mobile nodes, despite being energy constrained should provide continuous assistance to rescuers. However, since transmission implies high energy consumption, the ideal formula will be (1) for a mobile node to try transmitting only when the channel is available so as to escape collision and, (2) it should transmit at the lowest power needed such that the transmission range covers at most up to the receiver. This has led to the development of power-aware routing protocols where some research focused on the implications of power consumption of nodes in an ad hoc emergency MANET [14]. As a result of minimising the transmission range, spatial reuse is increased and thus leading to a subsequent boost up in network throughput. However, without a consistent support for real-time data transfer, ad hoc network will not be the supporting platform that to mitigating the stressful operations in an emergency system.

2.2 Real-time Multimedia Distribution with Ad Hoc Network

The characteristics of ad hoc network, mainly limited bandwidth and mobility, pose a challenge on the distribution on the real-time multimedia. Also, a highly variable end-to-end delay prevails due to the multi-hop nature of nodes' communication. Furthermore, with the highly dynamic topology of ad hoc network, it was shown that mesh-based multicast protocols outperformed tree-based ones in mobile scenario since alternate routes available increases robustness [8]. The use of multiple paths has also become a salient feature towards increasing error-resiliency in multimedia distribution using ad hoc netwdorks [15, 16, 17].

There are two main coding strategy for the distribution of video: (1) Layered Coding, in which there is a base layer, that needs to be present and provides the least acceptable quality, and enhancement layers, that bring quality enhancement to the base layer. (2) Multiple Description Coding (MDC), where each layer can independently reconstruct a stream of basic quality. With MDC, additional layers add up to quality. It has been shown that MDC approach is more error-resilient to packet losses than Layered Coding [18].

The improvement of end-to-end performance and the multicasting of multimedia using MDC have been the main research topics in the area of video streaming recently [19, 20, 21, 22, 23, 24]. Serial Multiple Disjoint Trees Multicast Routing Protocol (Serial MDTMR) outperformed single tree multicast communication. Serial MDTMR is based on On-Demand Multicast Routing Protocol (ODMRP), which is very effective and efficient but as the number of senders increase, overhead increases rapidly [8, 24]. Moreover, multiple source trees was also proposed for multicasting multiple description video over ad hoc networks [24].

Table 1: Summary of comparisons of common multicasting protocols

	High mobility supported	*Route discovery delay*	*Multicast control overhead*	*Reliability*	*Scalability*	*Unicast dependence*	*Flooding*	*QoS support*
ASTM [39]	*M*	*L*	*H*	*L*	*G*	*Y*	*N*	*N*
AMRoute [40]	*P*	*L*	*H*	*L*	*P*	*Y*	*Lm*	*N*
MLANMAR [41]	*M*	*L*	*L*	*H*	*G*	*Y*	*Lm*	*N*
CAMP [42]	*M*	*L*	*H*	*M*	*G*	*Y*	*N*	*N*
MCEDAR [43]	*M*	*L*	*H*	*M*	*M*	*Y*	*N*	*N*
MZR [44]	*M*	*H*	*M*	*M*	*M*	*N*	*Lm*	*N*
MAODV [45]	*P*	*H*	*L*	*L*	*P*	*Y*	*N*	*N*
DMRP [46]	*P*	*H*	*L*	*L*	*M*	*Y*	*N*	*Y*
RBM [47]	*M*	*H*	*L*	*M*	*G*	*Y*	*N*	*Y*
AMRIS [48]	*P*	*H*	*L*	*L*	*P*	*N*	*Lm*	*N*
LAM [49]	*M*	*H*	*L*	*L*	*G*	*Y*	*N*	*N*
ODMRP [50]	*G*	*H*	*L*	*H*	*M*	*N*	*Lm*	*N*
FGMP [51]	*M*	*H*	*L*	*M*	*P*	*N*	*Lm*	*N*
RMRP [52]	*G*	*H*	*L*	*H*	*P*	*N*	*Y*	*N*
GEOCAST [53]	*G*	*H*	*L*	*H*	*P*	*N*	*Y*	*N*
PBM [54]	*P*	*M*	*0*	*L*	*G*	*N*	*N*	*N*
DDM [55]	*G*	*L*	*L*	*H*	*P*	*Y*	*N*	*N*
MHMR [56]	*G*	*L*	*M*	*H*	*G*	*N*	*N*	*Y*
AQM [19]	*P*	*M*	*M*	*M*	*M*	*N*	*Lm*	*Y*

L = Low, M = Medium, H = High, P = Poor, G = Good, 0 = Zero, Lm = Limited, Y = Yes, N = No.

2.3 Scalability of Ad Hoc Network protocols

Scalability of multicast protocols is whether an acceptable level of service is maintained as there is an increase in either (1) the number of nodes in the network or, (2) the number of groups or, (3) the number of groups' members. This is directly related to the overhead incurred from control messages for group management. This can be regulated by reducing (1) the frequency of sending update information, and (2) the size of the update message [25, 26].

A study showed that per-node capacity as well as the network capacity largely depends on the locality of communication as the network grows [27]. Also, an evaluation of the scalability of different routing methodologies for ad hoc networks is given in [28]. Moreover, GPS assisted routing, for example [35, 36, 37, 53], scores in scalability by aiding in a more efficient unicast and multicast transmissions of data when location is known.

It has also been shown that unlike with unicasting, under the multicast mode, network capacity can increase significantly in massively dense network [29]. Performance estimates has revealed an overall reduction in network load by $O(\sqrt{n})$ for n multicast group members. Moreover, the throughput capacity of ad hoc networks can increase significantly where delay-tolerant applications can take the advantage of nodes' mobility [30].

3. SENCAST

The aim of SENCAST is to efficiently disseminate information to support emergency operations using a large ad hoc network. The objectives are (1) to be a scalable protocol for very large ad hoc network, (2) to exhibit very low overhead for group management, (3) to be highly resilient, (4) to provide support for real-time emergency activities, (5) to allow communication between a sender and a distant group of receiver(s), (6) to be efficient to the high mobility anticipated in an emergency area, and (7) to maintain a level of QoS.

3.1 Just-in-time logistics

All police stations, police motor vehicles, houses and poletops (at predefined intervals) can be nodes of an ad hoc network. Moreover, dynamic nodes that need to be located or that need to be properly identified are equipped with a GPS receiver while static nodes (e.g. poletops) store their preset position's details. Nodes can request/receive maps or criminals' portraits… as and when needed. Using GPS coordinates from event notification messages in case of theft, fire…, they will be able to determine where exactly the event is occurring, using the received maps, and also what they are supposed to do with the timely dissemination of coordination information. Sensor nodes can also be deployed in the event of emergency in weakly connected areas to bridge the connectivity gap of the ad hoc emergency network.

3.2 Protocol support and requirements

Control centres, lying far from the emergency area, disseminate real-time data/information to all the nodes within a specific region. Receivers will be able to establish a one-to-one duplex channel to any of the control centres efficiently, based on the location and IP of the latter; this information is attached with packets received. In short the protocol establishes routes based on *(1) known IP and known location (unicasting)* and *(2) unknown IP and known location (multicasting)*. The protocol also enables transmission based on *(3) known IP and unknown location (unicasting)*. However, due to the lack of context information in the third case, the protocol may operate inefficiently.

The following are assumed when running SENCAST protocol: (1) dynamic nodes are equipped with a GPS receiver, (2) group mobility in the emergency area is based on the Reference Point Group Mobility (RPMG) model [31], (3) the sender has an approximate GPS coordinates of the emergency area, (4) the sender's mobility is low during route discovery, and (5) bi-directional links exist between nodes. The RPMG model reflects emergency operations, where an accident or rescue has a logical centre with rescuers collaboratively moving in relation with the logical centre of the emergency area.

3.3 Route discovery

When a node needs to send a packet, it looks up its tunnelling table which stores the next hop to forward the packet of a multihop destination. The tunnelling table also keeps record of the reverse path forwarding for each route. However, when the destination is not within transmission range and cannot be found in the tunnelling table, route discovery is initiated with an *InitpackMessage*. There are three possible cases that delimit the range of route discovery packets transmission which are based on (1) *known IP and unknown location*, (2) *unknown IP and known location*, and (3) *known IP and known location*.

3.3.1 Known IP and Unknown Location (unicasting)

The missing parameter, location, in this scenario can make the route discovery process very inefficient. One way to limiting the extent of this multihop route discovery is by allowing nodes only within a certain distance from the initiator to forward the initpackMessage. Each node receiving an *InitpackMessage,* checks whether it is within a certain distance from the sender and reserves the required resources before forwarding the message to its neighbours. However, if the required resources are unavailable, the message is simply discarded. In the case that the destination is reached, an acknowledgment, *AckpackMessage*, must be received along the reverse path before a timeout reverts the reserved resources.

In the case of a timeout before a route acknowledgement is received, the source will reinitiate route discovery within a range that doubles what was previously covered. This procedure is applied continuously until a threshold is reached or a route is found before the timeout.

When the destination receives the first route discovery message, it generates an acknowledgement message which is sent along the reverse path taken by the *InitpackMessage*. This will not only confirm the existence of a route to the destination but each node along the route adds a reverse entry in the tunnelling table which will allow a full duplex communication channel.

3.3.2 Unknown IP and Known Location (multicasting/sencasting)

Sencasting is used to send a message to all nodes in a particular area. The sender does not need to be aware of the IP addresses of the receiving nodes but an approximate logical centre of the emergency area is required along with the radius of the transmission range from specified centre. While the coordinates of the source and logical centre of emergency area allows nodes to determine whether they are within the forwarding zone, the coordinates of the 'epicentre' and radius, allows the determination of whether a node is within the virtually bounded emergency area that receives sencast messages.

If the sender is outside the defined emergency area, it will search its tunnelling table to look for a node that is within the emergency area. If the result is unsuccessful, it will try to find a route to that emergency area using *InitpackMessage*. However, since the location of the destination is known, the route discovery packet is sent in the direction of the specified location only. An end to *InitpackMessage* forwarding is reached when nodes inside the emergency area will respond with *AckpackMessages*.

The first *AckpackMessage* received implies that the sender can start sencasting to that area as the appropriate entries in the nodes' tunnelling table along the path have been set up. However, to increase the resiliency of the protocol in transmitting video with the emerging Multiple Description Coding of video or images with progressive coding, the sender take into consideration other *AckpackMessages* received for the same location. Each path will carry the different layered descriptions to the same destination area. If only one acknowledgement is received, the sender can request for route discovery by changing the delimitations of the virtual forwarding zone. That is, the route discovery for others paths is delimited with different virtual areas; the initial one, Zone 1, is delimited by linear extent between the sender and the centre of the emergency area and ∂, relative to the radius of the emergency area. While Zone 2 and Zone 3 start from the shown logical centre line and extend to their corresponding side by ω and ℓ respectively. Figure 1 illustrates.

3.3.3 Known IP and Known Location (unicasting)

The route discovery for unicasting with known IP and known location will be similar to the sencasting mode but where instead, only the receiver will acknowledge the sender. In this case also, the sender can request for multiple paths to the receiver by requesting for routes to the same location and IP bounded by different virtual areas.

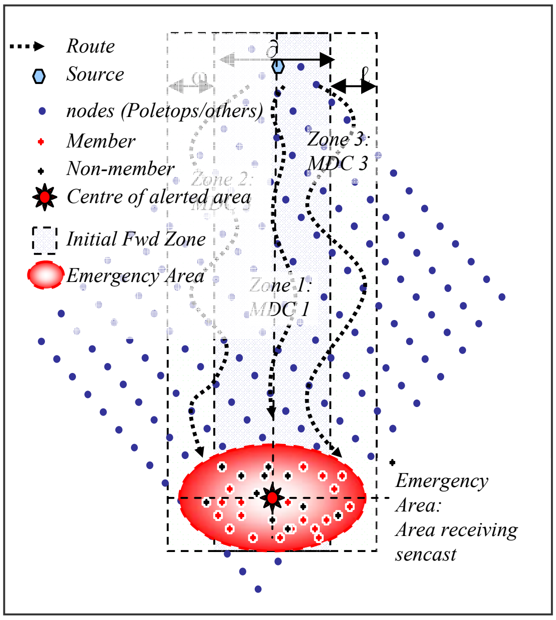


Fig. 1 Sencasting Multiple Description Coding with multipaths in different zones to the emergency area.

In all the above cases, an AckpackMessage plays a crucial role in establishing a route between two parties. In fact this message is confirming the reservation of the resources and at the same time establishing a reverse path for duplex communication. In the case of sencasting several alternate routes may be found while in unicasting mode, only one path is found. Therefore, during the establishment of unicast routes, all AckpackMessages are cross-acknowledged with an AckackpackMessage.

3.4 Route Discovery with Known Location and Overloaded Nodes

Route discovery is considered unsuccessful after a specific *initpackMessage* timeout. This will allow all nodes that received the message for route discovery to revert resources or the corresponding table entries. The main causes of route discovery timeout in the case of *known location* are due to (1) malfunctioning nodes, or (2) overloaded nodes inside the forwarding zone which prevents discovery messages from reaching the destination. In this case, the initiating node will try to rediscover a route within a larger forwarding zone.

The forwarding zone for the initial *initpackMessage*, being an area mainly defined by ∂ and the distance between the source and the centre of the emergency, could not allow the latter to get though to its destination due to the fact that some nodes which was unable participate in the searching activity. Therefore, after the discovery timeout, the same message is allow to be forwarded in a larger region, twice the size of the previously virtually defined region, therefore allowing the participation of more nodes which leaves a higher probability for the message to reach its destination. The forwarding zone grows exponentially after each timeout until a route is discovered to the destination.

3.5 Tunnelling

When the route discovery initiator receives the acknowledgement, a path is now available to the destination and the node can send the IP data packets to the appropriate next hop as a tunnelled message. In the unicasting case, packets are sent to its destination. While in the sencasting case, the sencasted data is tunnelled to a node inside the emergency area where ultimately it is sencasted; that is, the data to be sencasted is encapsulated in a unicast payload where it ultimately de-encapsulated at the destination node and smartly broadcasted in the required region. While receivers of unicast packets can use the same route for replying the sender, receivers of sencasting packets need to initiate route discovery with known IP and location before they can forward data packets to the sencast sender. Note that the IP and approximate location of the sender is part of the header information of the packets.

3.6 Sencasting

Sencasting is a new multicast paradigm that will be used in large ad hoc emergency network system. The high mobility in an emergency area makes it inefficient to send control messages to keep track of neighbouring nodes' position and membership for multicast trees maintenance. Instead, based on the affinity of nodes movement in an emergency operation, a smart flooding scheme is used for the multicasting instead of periodically flooding the emergency area to sustain a tree or mesh network of group members. A node will broadcast a sencast message received if the additional coverage is worth.

3.7 Mobility

While some of the static nodes in the emergency network may remain stationary for a long period of time, other mobile nodes, especially those inside the emergency area may be of high mobility. The protocol adapts to mobility of (1) the source, (2) the intermediary nodes participating to tunnelling, and (3) the receiver or the group of receivers in the emergency area.

3.7.1 Adaptation to source mobility

At regular intervals, nodes send *HelloMessage*, containing an IP address plus a location, to its neighbours. When the source finds that it will be out of the transmission range of a NEXTHOP which is of an active communication channel, it broadcast a *ConfigMessage* in the required zone using the principle of expanding ring search until it receives a corresponding acknowledgement. *ConfigMessages* are rebroadcasted until the TTL of the message is zero or a node that is on the tunnelling path receives the same and acknowledge with an *AckConfigMessage* which mends the path up to the source. In the case that a node receives two or more *AckConfigMessage* for the same route configuration, it retains the NEXTHOP information from the node which is closest to the destination.

3.7.2 Adaptation to tunnelling path mobility

Tunnelling path mobility relates to the movement of nodes that are along a communication channel. Despite that most of the nodes contributing to tunnelling path will be static nodes of the emergency network, the protocol also adapts to moving nodes along the tunnelling path. A node that is going to be out of transmission range from either its PREVHOP or NEXTHOP sends a *ConfigMessage* to the PREVHOP which in turn send the same using the expanding ring search principle until an acknowledgement is received and the route is reconfigured. The concept is similar to adaptation to source mobility but here a node receives a *ConfigMessage* from its NEXTHOP and finds a path to mend the route.

3.7.3 Adaptation to the mobility of the emergency area

Mobility of the emergency area corresponds to the affinity of the movement of the group of rescuers. Depending on the direction of the group movement, there exist two types of path maintenance: (1) where only path extensions may be needed; this can be configured using the same previously mentioned principle, i.e. using expanding ring search, for route configuration. During the maintenance, on a temporary basis, the node at the end of the tunnel can broadcast the data packets which will reach the emergency area in two or three hops. (2) The direction taken by the group may compel the source to initiate route discovery within a another virtual region instead of reconfiguring existing route, if this leads to inefficiency in terms of hops needed to reach the emergency area.

When members inside emergency area observe a significant change in the GPS coordinates received, they send an *EmergencyHelloMessage* to the source. Figure 2 illustrates a group movement that relative to the source location will imply the disposal of one route using a soft state approach, through timeout when not in use. Then the source initiate discovery in another region. On the other hand, the two other existing paths can be extended using the expanding ring principle.

4. Application scenario – Emergency responders

The three basic expertise/services required in the event of an emergency response include (1) fire-fighting, (2) law enforcement by the police and (3) emergency medical services [32]. However, despite being given different titles, each individual may provide more than one service. For example, a fire-fighter, being cross-trained as a first aid medical officer, can respond to on site medical calls in the absence or lack of medical personnel on site. In other cases, a policeman may volunteer as a fire-fighter. In order to take the advantage of all the possible eventual circumstances, it is imperative that all on site responders are aware of the ongoing operations within all the services providers.

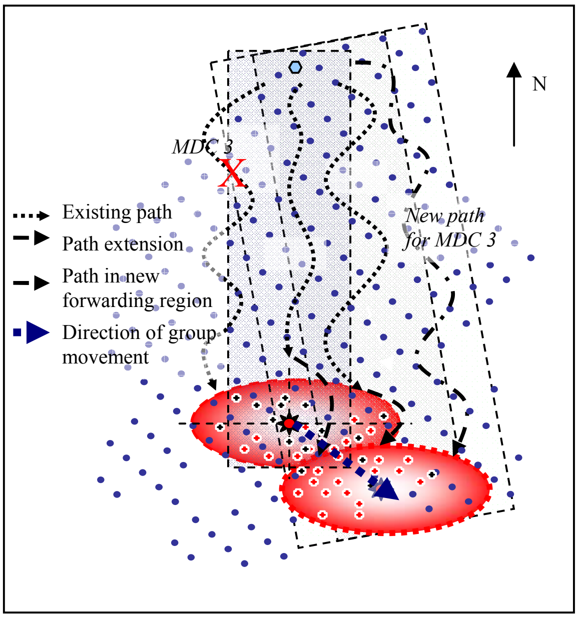


Fig. 2 Group movement requiring route discovery

In this scenario, a building is on fire and multi disciplinary bodies arrive on the site with their PDA's. Their respective operation manager or the inter-disciplinary coordinator may be located on site or as far as the coverage region of static nodes allow. *SENCAST* allows the coordinators to send messages to all the rescuers in a particular area; this is made possible by sending with the *Known Location and Unknown IP* option. All the rescuers will be aware of the moves and operations undertaken or in the pipeline. The location is defined by an approximate coordinates of the logical centre of the emergency region with a radius or diameter.

Any receiver in the emergency receiving a *sencasting* message may query the sender about the information received or request for additional resources or data or building plans… The *Known location and Known IP* of the protocol is used to request the required information. The communication will be a one to one, unless the sender supposes that the information requested may be vital to other rescuers as well. It should be noted that a *sencasting* message contains not only the IP address of the sender but also its current location.

Any node inside the emergency area needing help from neighbouring active rescuers can request for same by sending to *Known Location and Unknown IP*, where the location is defined the emergency area.

In the worst case, if neither the sender is aware of the location of the emergency operations nor any receiver is aware of the servers or coordinators position, the last option for *SENCAST* will be *Unknown Location and Known IP*. It may be necessary for a receiver to be at least aware of its coordinator's IP address and possibly its position if the latter is static (e.g. police station/hospitals/etc.). Then, whenever and wherever emergency responders are performing on an ad hoc basis, efficient communication can take place. The receiver will be able to contact its coordinator/server which will in turn be able to determine an approximate position of the emergency area once it receives a message.

5. Simulation study

The objectives of conducting the simulation study are mainly (1) to show the scalability of SENCAST's route discovery process for use in large ad hoc networks when the source and the destination(s) are lying at opposite extremities of the network and the destination's location is known, and (2) to determine the suitability of the protocol for real-time data transmission.

5.1 Simulation environment

The simulation was done using JiST/SWANS wireless network simulator [38]. SENCAST was simulated with client-server applications on networks with more than 100,000 nodes. This was achieved on a laptop of 1.6 GHz processing power and 1 GB memory. Table 2 and Table 3 show the values of the mentioned parameters used in the simulation. The distances between the communication endpoints were chosen arbitrarily but are maximised with respect to the simulation area. Thus, the simulation results reflect the worse possible scenario in terms of distance of the communication link establishment. Similar simulation cases were repeated for scenarios of network with malfunctioning/overloaded nodes (0%, 25% and 50%) and either limited or unlimited resources available per node.

5.2 Geodetic to 2D local grid

Nodes in the simulation grid were assigned X and Y coordinates directly to gain in processing time by avoiding the conversion from the geodetic system (GPS output: longitude, latitude, altitude) to the local system. The formulae in [33] can be used to transform the output of GPS into 2D plane and the following is applied by nodes to find out whether a node lies inside the forwarding region:

With reference to Figure 3, *Src* is looking for a route to *dest*, with known location. At some point in time, an arbitrary node *p* receives a route discovery message and should decide whether it should forward the received message by determining whether it lies in the current forwarding zone of *src* to *dest*. The initpackMessage *p* received contains the location of *src* and *dest*, and the range of the forwarding zone.

Using the location of the source and destination, *p* can derive the equation $Y = m(X) + C$. Then *p* needs to finds out the distance between itself and the perpendicular intersection, *q*, with the imaginary line joining *src* and *dest*. Using the fact that the equation of the line that joins *p* and *q* is $\boldsymbol{Y = -1/m(X) + K}$, and at the intersection $\boldsymbol{Y = m(X) + C = -1/m(X) + K}$, *p* derives *q's X* and *Y* coordinates after calculating:

m = (src.Y – dest.Y)/(src.X – dest.X), C = src.Y – m(src.X), K = p.X + m(p.Y)
If (src.X – dest.X) is not equal to 0 and m is not equal to 0, then: ***q.X = (K/m - C)/(m + 1/m), q.Y = m * q.X + C***
If (src.X – dest.X) is not equal to 0 and m is equal to 0 (horizontal line), then: ***q.X = p.X, q.Y = C***
If (src.X – dest.X) is equal to 0, m is equal to ∞ (vertical line), then: ***q.X = src.X or q.X = dest.X, q.Y = p.Y***

Finally *p* calculates the distance between *q* and itself. If the distance is less that the specified forwarding zone range and *q's X* or *Y* coordinates lies between the endpoints *src* and *dest*, then *p* forwards the received *InitpackMessage*.

Table 2: Simulation parameters

Parameter Description	*Value(s)*
Nodes distribution	*Uniform*
Hello Message interval	*10 s*
InitpackMessage timeout interval	*15 s*
AckpackMessage timeout interval	*1 s*
Tunnelling entries timeout	*15 s*
Wireless transmission strength	*15 dBm (up to 500m)*
Distance between adjacent nodes	*200 m*
Number of nodes	*100; 400; 1,600; 6,400; 25,600; 102,400*
Initial forwarding zone range	*400 metres * 2*
Forwarding zone threshold	*100,000 metres*
Data packet size	*< 64 bytes*
Bandwidth	*1 Mbit/s*
Frequency	*2.4 GHz*
Mobility	*Static*
Jitter before sending a packet	*10 – 15 ms (random distribution)*
Diameter of emergency area	*2000 metres*

Table 3: Additional Simulation parameters

Number of nodes	***Configuration***	***Area size (Km^2)***	***Distance between server and emergency area (metres)***	***Distance between server and client (metres)***
100	*10 * 10*	*4*	*935*	*1,224*
400	*20 * 20*	*16*	*3,741*	*3,594*
1,600	*40 * 40*	*64*	*9,542*	*9,392*
6,400	*80 * 80*	*256*	*18,358*	*18,221*
25,600	*160 * 160*	*1024*	*40,288*	*40,133*
102,400	*320 * 320*	*4096*	*84,072*	*83,923*

5.3 Scalability

The scalability of ad hoc network multicasting protocols largely depends on the control packets for establishing routes, maintaining groups and reconfiguring routes. Since there is no overhead associated with groups and routes' reconfiguration are localised, the main determinant of scalability for SENCAST is route discovery.

The sender and receiver for the simulation were lying at two extremes of the simulated network space. This should have implied that the number of nodes contributing to the route discovery process must be very high. But the simulation shows, from Figure 4, that as the number of nodes in the network increases, the percentage of nodes involvement in route discovery goes down. This is mainly because the forwarding zone extent in width remains the same and having therefore a smaller area relative to the network growing in size/nodes.

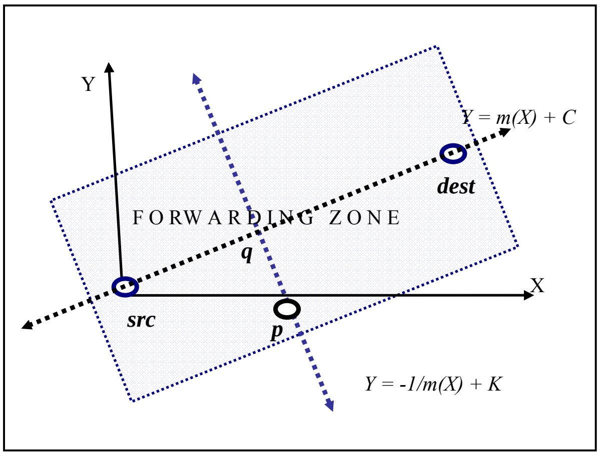


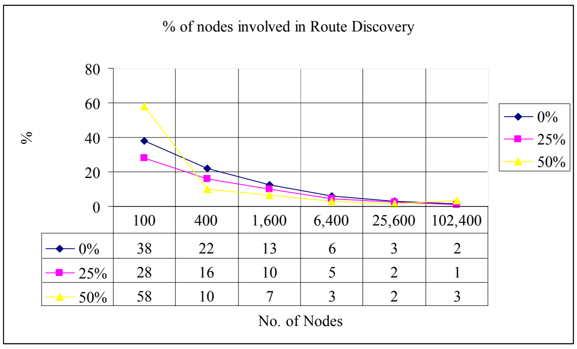
Fig. 3 Route discovery forwarding zone derivation on a 2D local grid.

Figure 5. shows the percentage of nodes involved in route discovery between endpoints that lies at two opposite extremes of the network with respect to different widths of the forwarding zone (400 metres, 300 metres and 200 metres). The results also implies that for endpoints which are less than 40 kilometres apart, the control packets sent for route discovery can be significantly lower with a reduced initial forwarding zone. Same applies for sencasting to a distant group of receivers.

5.4 Real-time data transmission

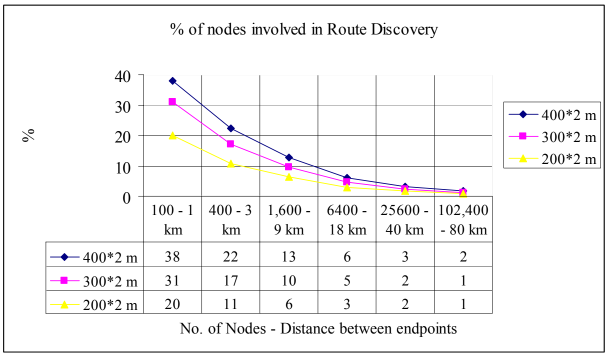
The parameters that should be under controlled when transmitting real time data are mainly (1) *startup delay* (2) *end-to-end delay* (3) *jitter, and* (4) *round-trip delay*. Startup delay needs consideration for interactive applications where an immediate response is required at the start of a new session of communication. On the other hand, end-to-end delay may seriously affect human-to-human interaction if replies take longer than one is expecting, while the maximum end-to-end delay implies a threshold to streaming data at a constant bit rate. Finally, for successful human-computer interaction, the round-trip delay must be as short as possible. Therefore, in order to avoid jeopardising emergency operations, the above mentioned parameters must be within the norm of the applications for a successful emergency response.

The startup delay is the time taken from the request for a route up to the receipt of an acknowledgement for the availability of the route. Figure 6 shows that startup delay was less than 10 seconds for all routes discovered where sender and receiver were at opposite extremities in the network.



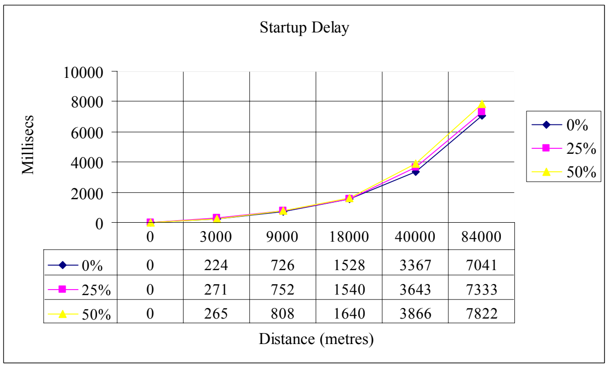
	100	400	1,600	6,400	25,600	102,400
0%	38	22	13	6	3	2
25%	28	16	10	5	2	1
50%	58	10	7	3	2	3

Fig. 4 Nodes involvement in route discovery.



	100 - 1 km	400 - 3 km	1,600 - 9 km	6400 - 18 km	25600 - 40 km	102,400 - 80 km
400*2 m	38	22	13	6	3	2
300*2 m	31	17	10	5	2	1
200*2 m	20	11	6	3	2	1

Fig. 5 Nodes involvement in route discovery w.r.t forwarding zone.



	0	3000	9000	18000	40000	84000
0%	0	224	726	1528	3367	7041
25%	0	271	752	1540	3643	7333
50%	0	265	808	1640	3866	7822

Fig. 6 Startup delay for sencasting.

Simulation results also showed that the mean end to end delay approximately doubles as the distance between the two communicating end-points more or less doubles. Moreover, when the distance is less than 40 kilometres between the two communicating endpoints, an acceptable mean round trip delay can be achieved. The round-trip delay is mainly affected by the multihop routing fashion and the delay before transmission by each node. Since the protocol is reactive, the jitter was highly affected by the startup delay since the first message waits for the protocol to set up a route before the packet containing the message can be routed to the destination. Finally, whenever a route exists, with sencasting, the delivery ratio inside the emergency area was 100% implying that the smart flooding worked fine.

6. Summary of Observations

The reactive route discovery process was limited by the forwarding zone that guided the initiation packets towards the destination. The only roadblock that caused an increase in the route discovery delay is the presence of malfunctioning nodes or resource-poor nodes along the discovery way. The end-to-end and round-trip delay were acceptable for human-computer interactions when the distance between the two endpoints was less than 40 km.

Multicast group inside the emergency zone was unmanaged. It is useful for multi-disciplinary team to be kept aware of the move of the other rescuers. This has led to zero multicasting control overhead. All nodes inside the emergency received a sencasted message. But, at times, more than one copy of the same message reached a receiver. Although the simulation has not included the multiple paths, this would certainly ensure the reliability of the communication link. Moreover, in the instance of one-to-many communication path establishment, the source had the choice among several alternate routes to reach the destinations.

The protocol moved towards a very low participation of nodes in route discovery as the network grew in size despite the sender and receiver were at two extremes. Overheads during path establishment could be further reduced by diminishing the initial forwarding zone. Moreover, since the group management was replaced by a smart broadcast, the overheads associated with trees configurations and reconfigurations were wiped out.

There was no dependence on an underlying unicast protocol. SENCAST is a novel protocol that allowed both a one-to-one and a one-to-many communication link channel. The flooding method used in route discovery was bounded by the forwarding zone while in the emergency area a smart flooding allowed the efficient dissemination of messages.

The reservation of resources was required before a node could forward a route initiation packet. The level of required resources could be possible with additional fields in the same packet.

The protocol was loop-free. A particular data message was sent only once by a node while control messages could be resent after a timeout occurs. Packets were not sent outside their respective forwarding regions and all reconfigurations were localised.

The protocol being reactive-based allowed the efficient use of energy and bandwidth; no control packets were sent to maintaining idle routes proactively.

Despite that there has not been any simulation for mobility, the support for high mobility was ensured in the emergency area as no multicast tree was to be maintained. Moreover, the protocol has been designed to operate even if the static regions, with poles, become dynamic. Source and emergency site mobility is also efficiently supported with low overheads due to the localisation of route reconfigurations.

7. Protocol Optimisations

The efficiency of route discovery and sencast message dissemination can be improved using the self-pruning method [34]. Each initpack/sencast packet sent should contain the list of neighbours of the sender. The receiver of the initpack/sencast message should cross check its own adjacent nodes list with what has been piggybacked with the received message. If no additional node is reached, the message is discarded.

Given additional context information like the size of the network and density of nodes, the protocol should derive the width of the optimal forwarding zone and its threshold. This will seriously impact on the efficiency and true scalability of the protocol.

In the case of route discovery for sencasting, the sender may be acknowledged with several routes that will allow the sencast message to be disseminated to the required region. However, the path chosen to the emergency area must be a stable so as to minimize route maintenances. This can be made possible with additional context information (for e.g. an average of nodes' velocity along the path) that could be sent back through the ackpack to the route discovery nitiator.

The timeout associated with route discovery is sensitive to mainly (1) the distance between sender and receiver, (2) processing capacity of nodes, and (3) load on forwarding nodes. It is therefore imperative for the protocol to be tested in the real world scenarios with the appropriate hardware devices to determine the optimum value for the timeout. Otherwise, the protocol may be very inefficient in discovering routes or in the worse case, no route is found when even paths leading to the required destinations exist.

8. Conclusion

SENCAST, a new multicast paradigm for large emergency networks, finds route with (1) known IP and known location, (2) known IP and unknown location, and (3) unknown IP and known location. It extends the capability of geocasting routing protocols [35, 36, 37, 53], by allowing a more resilient transfer of real-time data like video by using (1) multiple description layer coding over multipath, and (2) allowing resource (bandwidth) reservation for QoS support. However, reserving resources like bandwidth can be very complex due to the wireless shared medium. Also, security in wireless ad hoc network is still in its infancy.

The suitability of delay-sensitive applications is bounded by the physical transmission limitation of the multihop routing which affected the end-to-end delays and consequently round-trip delays. This may have a serious impact on distant real-time interactive applications.

The protocol efficiently adapts to nodes mobility with localised reconfiguration. In the event of a shifting emergency area, the existing path is extended without the involvement of nodes along the existing path. Moreover, depending on the direction of movement of the source relative to the destination or vice versa, a new route is established based on the direction of movement. At the same time, stale routes are cleared using a soft state approach and the associated reserved resources are reverted.

SENCAST performs well on a very large scale ad hoc network as all control packets for route discovery and route maintenance is very low. The efficiency of SENCAST also relies on the careful choice of the initial forwarding zone and its threshold. Moreover, there is no overhead associated with group management, such as building and maintaining multicast trees. This has been possible mainly because of the affinity of nodes' movement in fulfilling emergency operations.

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