Robots and Humans Reconvening*

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Abstract – *When communication fails, our ability to reconvene depends on previous planning. Rally points are often used as a way of establishing a communication hub in the event of an emergency. But mobile ad hoc networks give us new capabilities. What is ultimately important is the time it takes to re-establish communication, which is a function of location, mobility, and the available connectivity. Some heuristics will work better than others, and certain situations favor the use of robots to facilitate communication, by forming an ad hoc bridge between isolated areas, or by acting as couriers. If software-defined radios are available, then strategies can be developed that periodically help recalibrate paths toward a rally point. The work has implications for search and rescue, robot design, and emergency response.*

Keywords: Human-robot interaction, machine autonomy, mobile ad hoc networks, emergency response, search and rescue

1. Introduction

Robots are often deployed into emergency situations. And while we try to build as much autonomy as possible into these robots, they need to communicate – with other robots, and with human operators.

But emergency conditions often break the existing communication infrastructure. We are interested in how to reason about the situations in which the infrastructure fails.

The issue is an important one in emergency response and search and rescue conditions, a favored domain for robotic research [e.g. 12, 16, 19]. Much of what we will discuss applies equally well to humans as to robots. Yet there is a reason to focus our thinking on the use of mixed teams. For emergency conditions are by definition harsh, and robots are often built to withstand harsh conditions.

Our general research questions are the following: how can we utilize the combination of robots and humans to best respond to emergencies? More specifically, how can we plan for conditions in which communications may be lost?

2. Scenarios

> *Scenario 1: A set of humans lose connectivity in an emergency situation. What should they do?*

A common experience when communication fails suddenly is to regret not knowing the locations and plans of those who one wishes to contact. Military manuals suggest planning ahead of time on a rendezvous, a rally point [e.g. 6]. Such manuals remind us that the rally point should be recognizable. But they give us little other guidance.

In practice, corporate planners sometimes print wallet cards for employees, with a set of designated rally points depending on the emergency encountered.

The anecdotal evidence is that such techniques work. After the terrorist attacks of September 11, 2001, Manhattan employees in companies without rally points lined up to try to leave the city – and spent many hours queuing for the few available ferries. Employees in companies with rally points reconvened within an hour.

Where should one pick the rally point? Probably toward the center of the group. One can imagine convening inside a building in an urban setting, or at a natural landmark in an uninhabited area. We use such strategies when we agree to meet at recognizable landmarks, such as underneath church spires or public clocks.

> *Scenario 2: A set of humans lose connectivity in an emergency situation. They have **ad hoc network** capability. What should they do?*

In such a scenario, we can consider the ad hoc network a backup for lost satellite or cellular communication.

> *Scenario 3: A **set of robots** loose connectivity in an emergency situation. They have ad hoc network capability. What should they do?*

We will first analyze the strategies for robots and humans together; in later scenarios we will discuss the differences.

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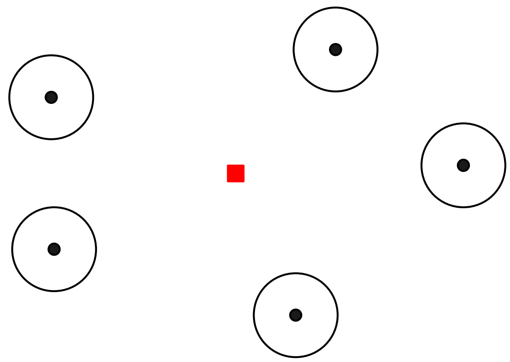

Figure 1.Disconnected entities with a rally point.

In figure 1, 5 entities with ad hoc communication devices are separated. Imagine these might be emergency responders, and normal satellite, radio, or cellular infrastructure has been disrupted.

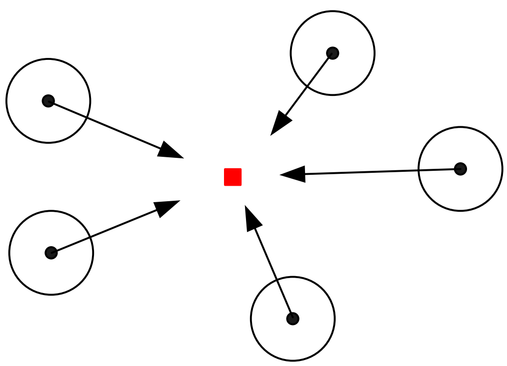

Figure 2. Movement toward a rally point.

Assuming there is a predetermined rally point, the entities might move straight toward the rally point. Distinct from the first scenario, they do not have to actually reach the rally point in order to get back into communication.

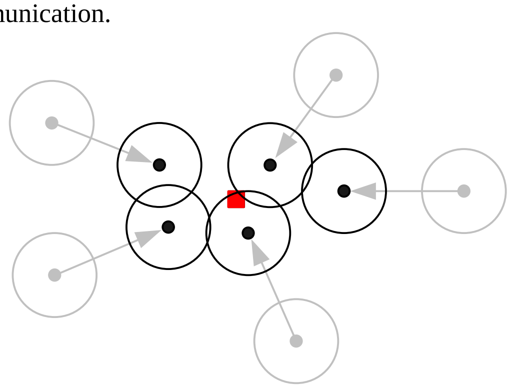

Figure 3. The entities are reconvened

Figure 3 shows that all will be back in contact when the furthest people or robots have only traveled half-way to the rally point. In other words, the amount of time to reconvene may be lessened if the entities agree to stop as soon as they establish contact with the rally point, especially if the contact is indirectly through the other ad hoc network nodes.

Now, how does one know where the rally point should be? There are two obvious ways. The first way is to designate a point ahead of time – "if we get separated, we move toward the tree". The problem with this is the point selected may end up being far away from all participants at the point at which communication is lost.

In a second method, while the network is connected, the positions of all participants might be continuously monitored, and an optimal rally point continuously calculated and stored locally in the ad hoc communication device. When communication is lost, the entities consult the latest stored rally point and proceed.

Assuming one has a rally point, how does one know when to stop moving toward that point? If one knows one's own radio coverage perimeter, one should stop moving when either a) the rally point is within the perimeter, or b) one connects to someone else who is already connected to the rally point, either by position or through other entities.

Because they are disconnected, the entities need a heuristic with which to proceed toward the rally point. One heuristic is to move in a straight line toward the rally points. This may be the simplest, but it is not the optimal strategy, if we our goal is to connect all entities as quickly as possible.

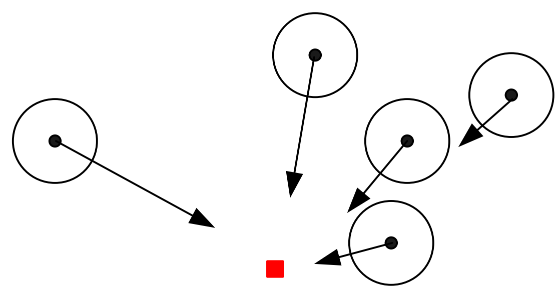

Figure 4. Straight-line convergence on the rally point.

Consider figure 4. If we converge on the rally point straight line, then the time to reconvene is controlled by the most separate entity, the one on the far left, as shown in figure 5.

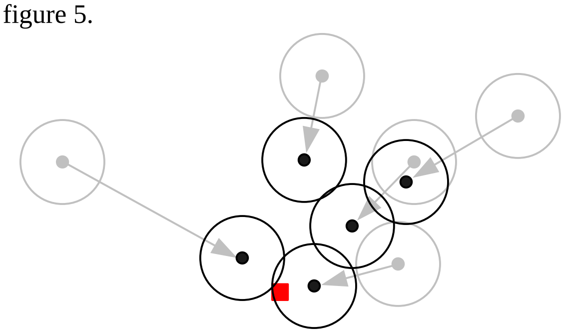

Figure 5. The resulting configuration from figure 4.

But, looking back at figure 4, we can see that most of the entities are clustered on the right – so a heuristic which shifts the paths of the cluster on the right toward the left, and sends the entity on the toward the cluster, will result in a shorter time to reconvene, as in figure 6

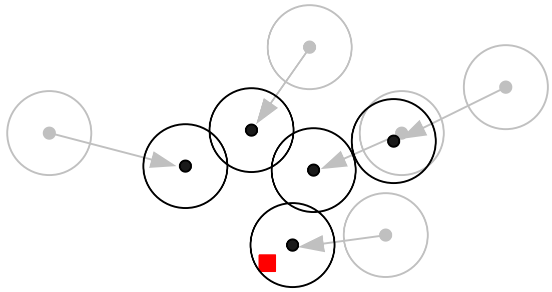

Figure 6. Planned routes in which entities move toward each other, not the rally point.

Such a heuristic would need to be precalculated – not only the rally point, but a path, would need to be continuously downloaded to the entities for use in case the group became disconnected. Alternatively, if one assumes visibility, then a simpler heuristic would be to head toward the closest stationary entity.

There are some interesting patterns that can occur.

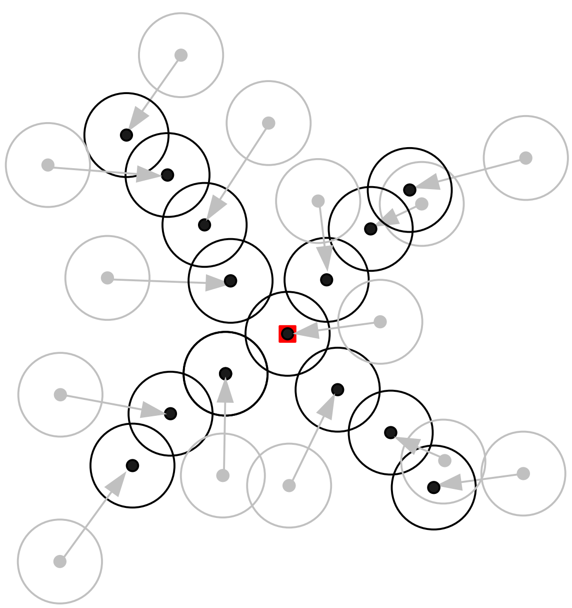

Figure 7. A cross configuration

In figure 7, a fairly dispersed team might end up reconfiguring in a cross-like pattern.

The idea of the rally point is based on physical presence – and ad hoc networks change this concept of presence. We can reconvene in patterns that have no specific rally point, as shown in figure 8 (the author thanks Paul Kolodzy for this idea [11]).

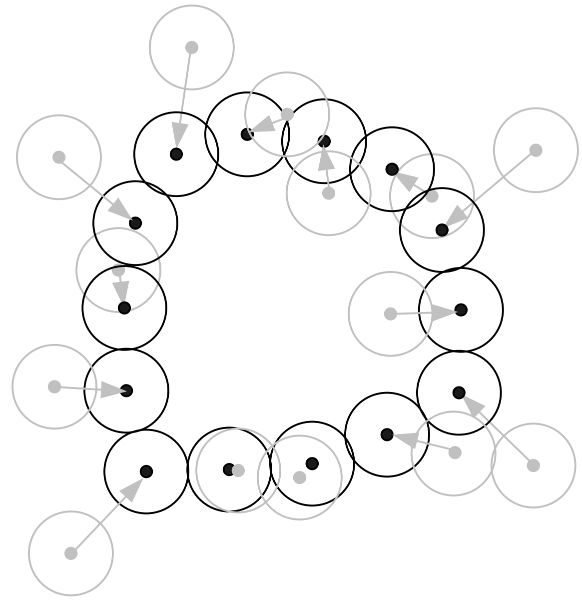

Figure 8. A circular configuration

Figure 8 has the same starting configuration of figure 7, shown in gray, and the greatest distance traversed is roughly the same as in figure 7. The circular pattern of figure 8 has the additional advantage that, even if one network node malfunctions, the rest of the nodes will still be connected. The cross pattern of figure 7 may be more useful in city environments, where travel on street grids may naturally reinforce such a configuration.

The problem with these more elaborate heuristics, in which everyone has their own path, is that several entities may get stuck or delayed – and during this period, the pattern will remain incomplete. The simple heuristic of figure 2 at least guarantees that whoever or whatever can get to the rally point will be connected to everyone else who can.

> *Scenario 4: A set of robot or humans loose connectivity in an emergency situation. They have ad hoc network capability, and there is a LAN in place with* ***local hotspots****. What should they do?*

Whereas in physical terms, reconvening means being in the same place, if there is a wide-area infrastructure, reconvening can be sped up by heading toward the closest hotspot, as in figure 9.

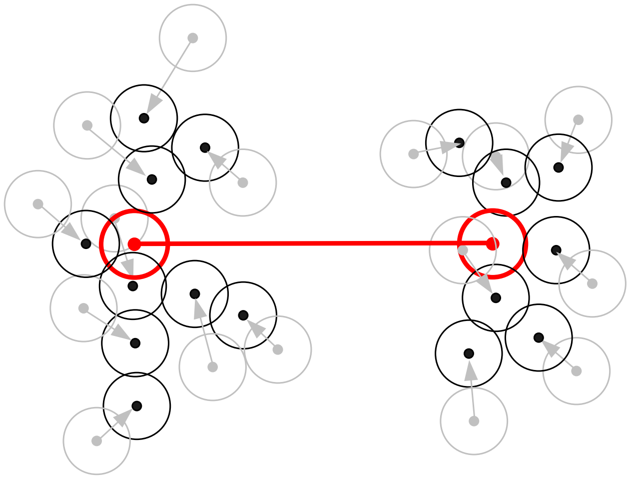

Figure 9. Using an existing LAN

The advantages become clear when the starting spatial distributions of entities are bimodal, as in figure 9. There are urban situations in which two parts of a city are separated by river; city planners might want to invest in a network bridge built to withstand emergency conditions.

*Scenario 5: A **mixed team of robots and humans** loose connectivity in an emergency situation. They have ad hoc network capability. What should they do?*

How is such a situation really different? The robot in an emergency may have the ability to withstand uncomfortable conditions. One might differentiate between the acting nodes, which will include humans, and the facilitating nodes, whose job it is to service the acting nodes. For example, if a bridge network such as that in figure 9 has failed, the facilitating robotic nodes might recreate it, as in figure 10.

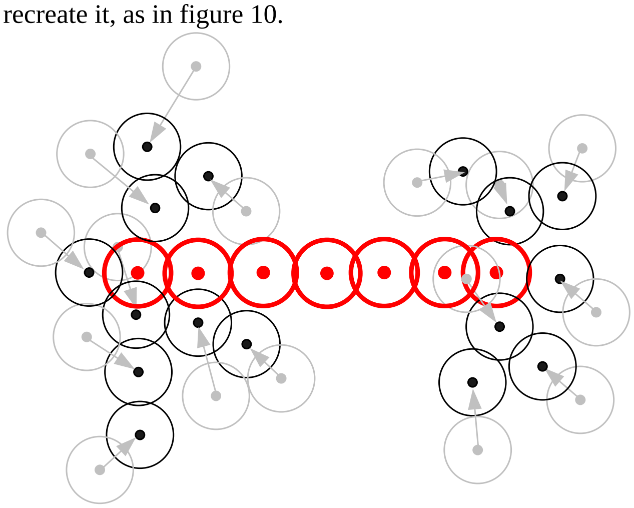

Figure 10. Building a permanent bridge across two distinct clusters.

The facilitating nodes might need to span a river – to do so we would need robots capable of moving and maintaining position in water, or moving and hovering in the air.

But what if this is impossible – if there are not enough robots of the right type to form a permanent LAN across a dangerous region?

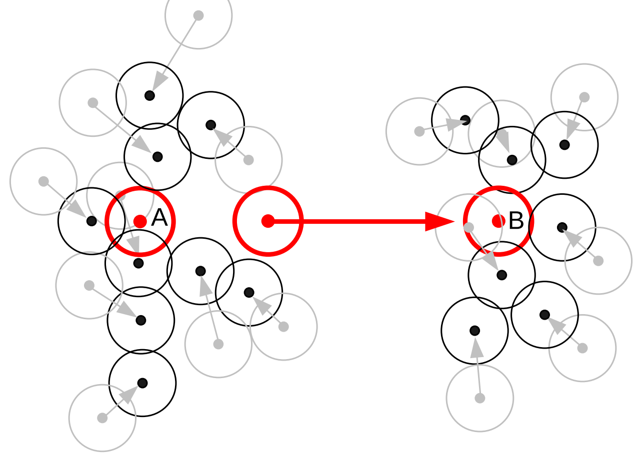

Figure 11. Using a courier to bridge two isolated groups.

Then one other solution is to assign to a robot a courier function, as shown in figure 11. Messages from the group attached to *A* are given to a robotic courier, who takes them to *B* for redistribution among the group attached to *A*. The communication within each cluster is instant; the communication distance between the clusters is the amount of time it will take the courier to pick up a message and bring it across.

This is similar in concept to runner techniques discussed in the literature on ad hoc networks [3].

*Scenario 6: A set of robot or humans lose connectivity in an emergency situation. They have ad hoc network capability with **software defined radios**. What should they do?*

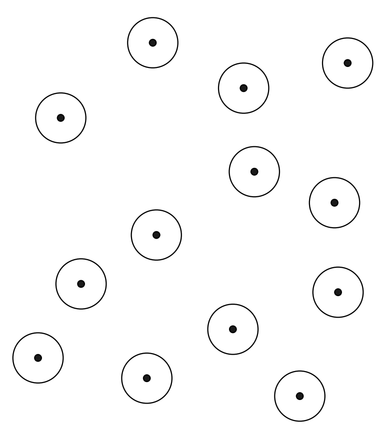

Figure 12. A set of disconnected nodes

Ideally, we would like to know where the other entities are as we reconvene. But this seems paradoxical – if we were already connected, we wouldn't need to reconvene.

However, radio coverage, radio throughput, and radio frequency are all in relation to each other. Software-defined radios provide many potential services [2], and can in principle allow us to alter frequency according to our application need. If we want wider coverage, we can lower the frequency of the radio, and communicate at lower throughput rates.

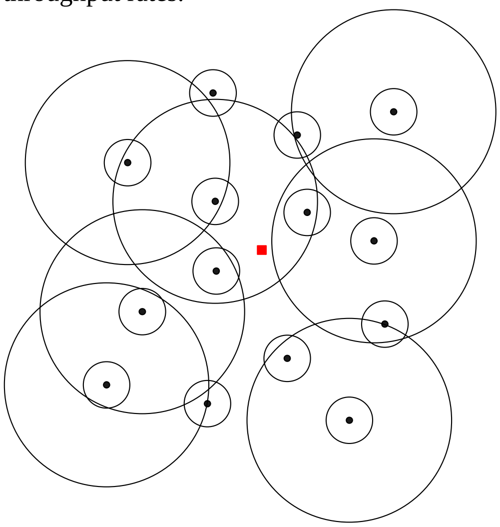

Figure 13. Wider circles represent lower bandwidth communication used for finding location

Figure 13 suggests how this might work. Periodically, the radio might drop to a lower frequency and transmit short messages indicating position. In figure 10, the wider circles around a subset of the nodes constitute a temporary reconvening to exchange coordinate information – communication would be very low bandwidth, and normal communication would recommence when the entities are within the range of each other as indicated by the smaller circles.

3. Related Work

Related to this work is research in mobile ad hoc networks, especially work in which mobility is used as a way of moving back into connection [3, 13]. Work on infostations is also relevant [9, 17]. Other work in ad hoc networks have focused on using movement to minimize energy use [8]. Also relevant are work on resource discovery [10] and rendezvous [14]. Robotics work has considered how decentralized devices can form shapes [7, 18, 20]. There is also research in amorphous computing which considers how large numbers of small robots might interact [1, 4, 5]

We have, in these scenarios, been optimizing the amount of time it takes for a collection of robots or humans to reconvene. How can we formalize this? In a concurrent paper, we have discussed a concept called communication distance, which is latency redefined to include the amount of time it takes to move into a position to establish a connection [15].

So in the examples we have discussed, we have been trying to find configurations which minimize the maximum communication distance of any member of a set. In other words, we want to choose our rally point, or our paths of movement, such that everyone is connected in the quickest possible manner.

Our parallel paper also alludes to a more general situation, in which we might not need to get all members of a collection back into contact, but just need some portion of the team back together again [15]. For example, it may be that a rescue team can still perform rescues if 30% of them can reconvene. In such a case, the rally point might be chosen centered in the largest cluster.

There are implications of what we have discussed for organizations. For collaboration between team members sometimes demands instant communication, and teams go to great lengths to establish multiple ways to connect, from face to face meetings to synchronized meetings over the Internet. Emergency response is a more drastic organizational environment, but the ideas may generalize to everyday interactions.

4. Conclusions

Whereas it is well-understood that ahead-of-time planning can help in emergency situations, there has been little research on which strategies may be optimal with respect to re-establishing communication. We have analyzed a number of scenarios, with the overall goal of finding strategies which minimize the time it takes for a team to reconvene.

Many of the techniques discussed apply equally to both humans and robots connected through ad hoc networks. But in situations in which robots and humans are mixed, the robots may potentially play a service role by bridging communication across natural obstacles or dangerous terrain.

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