Position Tracking in Voluntary Search and Rescue Operations

Øyvind Hanssen
Nesna University College, Norway
oyvindh@hinesna.no

ABSTRACT

This paper describes how enthusiasts from the radio-amateur and red-cross communities developed and applied position tracking to search and rescue services in Norway. This was based on the APRS standard which has been used by radio-amateurs for some time.

The document describes how radio-amateurs designed a tracking device which was robust and simple to use along with a web-based online service, a map server, to display positions along with other geographical information on electronic maps. The software for the tracker and the map server is free and open source. This system has been used in a number of search and rescue missions in Norway since 2009, to support decisions making in the command and control centre.

Keywords

GPS Tracking, SAR, Volunteers, Operational Picture

INTRODUCTION

In *search and rescue* (SAR) operations and other emergency situations it is important for operation leaders to have relevant information at hand in a timely manner. Many such operations involve rather ad hoc organisation, since they may depend on effort from various volunteers, amateurs and experts in different fields that are willing to help. There may be different organizations and different cultures involved, using current tools and collaboration patterns. It may be challenging to coordinate the effort in an efficient and effective manner while at the same time we do not want to compromise the safety of the involved personnel. In this context geographical information systems (GIS), can be useful in visualising information and presenting it on a digital map.

This paper describes how voluntary organisations in Norway are using position tracking in land based search and rescue operations. Radio amateurs (also called HAM-radio operators) and the Red Cross in Norway have for several years developed and used a system for tracking positions based on VHF radio communication and open source software. The system has been useful in many situations since its beginning in 2009 and according to police officers leading SAR operations (In a note by Anette Sjøli in Troms Police District to the radio amateur group, dated February 23, 2009), the usefulness of such a tracking system is mainly due to three factors:

1. The safety of personnel participating in search and rescue operations in the field.
2. Effective and efficient monitoring of the operations and coordination of resources.
3. Documentation of the operation after it has finished for the day. Planning of next day of operations. Post operation analysis.

Being able to visualise the situation and its development is helpful for the operation leaders in making decisions on what the next move should be. It reduces the need for other (verbal) communication and reduces the stress (in command and control centre). For instance, a quick look at the map can reveal that a search team is about to complete its mission and would soon need transport (from a location). Warnings can quickly be given if they accidentally move into dangerous areas. It is easy to monitor the progress of the operation. Decisions can be made in advance, increasing the efficiency of the operation. Hence the visualisation is sometimes called *tactical picture*, in particular if advance planning can be visualised as well.

We operate on information which is not just spatial, but also *spatio-temporal*. The first two aspects are about near *real-time* information, i.e. the display shows a *current* situation. The third aspect is about what has happened in the past and may be useful in tactical decisions. For instance it allows us to see what areas have been searched during the day, which is helpful in planning operations for the next day. In contrast to the two first aspects, significant amounts of data need to be stored and properly indexed in a spatio-temporal database to facilitate queries, for instance on what happened in a particular area in a particular time frame.

The rest of the paper is structured as follows: The next section describes some context for this work. Then we describe the design and implementation of a tracking system based on the APRS protocol which is widely used by HAM radio operators world wide. This includes a tracking device and an application to process and display positions on digital maps. Then we describe experiences from using the system in search and rescue and related types of operations. In the last part we first analyse issues of combining information from multiple sources and operating off-line. Then we discuss some pros and cons of the system before we conclude.

CONTEXT AND RELATED WORK

Information system support for emergency response (Jennex, 2007) is an active field of research and development. Here, spatial data plays an important role helping increase the *situational awareness* (Snoeren, Zlatanova, Crompvoets and Scholten, 2007; Zlatanova and Fabbri, 2009). This includes location of incidents, affected areas or buildings, location of rescue teams, victims, shelters, etc.

A known issue is how to create of a common *situational* or *operational picture* (Copeland, 2008; Norros, Liinasuo and Hutton, 2010; Wolbers and Boersma, 2013). In the literature, this concept has several definitions. The focus could be on creating a common understanding of the situation across multiple organisations and cultures participating in the decision making, or on the information systems supporting decision making. (Dilo and Zlatanova, 2011) develop a conceptual model for dynamic, operational information. They distinguish between *situational information* which is about the incident and its effect and *operational information which is about* active responses, processes, people and organisations involved. It is also useful to distinguish between *static information* that exists prior to incidents (like maps or positions of roads or buildings) and *dynamic information* which is produced during an incident.

Search and rescue

For search and rescue operations a number of information system tools exist for planning, coordination and decision support. This includes tools applying search theory and statistical models to help increasing the chances of success (Frost and Stone, 2001; Abi-Zeid and Frost, 2005). A known application of this in land based SAR is the Bicycle Wheel Model (Koester, 2008). This is easy to visualise and can be combined with tools to draw search areas, points or interest, to manage teams and missions, to write operation logs, and to track the position of teams. There are few commercially available land SAR tools and they are often not generally available since they often are designed for specific agencies or countries, are based on proprietary technology, etc. Examples include the British SARMan (Lewis, 2010), or Norwegian SARA (CMR Computing, 2015) used by the JRCC (Joint Rescue Coordination Centre). DISKO (Norges Røde Kors, 2007) was a joint project by the Norwegian Red Cross and others aimed to develop an affordable and more open tool for voluntary services. It proved to increase the efficiency of operations in pilot tests, but attempts to commercialise or to get further public funding failed.

The work described here focuses on one of the many parts of a information system for SAR, namely position tracking of teams, vehicles, etc. SARtrack in New Zealand (SARTrack, 2015) has many similarities with our work. They primarily do APRS tracking, but some aspects of search planning are supported as well. Our system aims to be an extensible platform where such functionality may be added as well as alternative data sources. Our project is focused on open source software, it is web-based and open, while most other solutions require platform specific programs to be installed on desktop or laptop computers.

THE DEVELOPMENT OF A TRACKING SYSTEM

Our tracking system based on APRS (Automatic Packet Reporting System) which is a open standard used by radio amateurs world wide. The fact that voluntary rescue services in Norway have adopted APRS does not exclude other technologies. In the following, the overall infrastructure is described, then the implementation of a portable tracker and an application for displaying tracking information on electronic maps.

Concepts

Location items can be either *stations* or *objects*. Stations have globally unique *identifiers* which typically are *radio callsigns*. Stations transmit *position reports* in order to update their positions or other associated information. Objects are *owned* by stations which report their positions. They have identifiers that are more freely chosen and not required to be globally unique. This implies existence dependency, but in the APRS protocol a station that transmits an object having an identifier owned by someone else, can in some cases be considered to take over the ownership. This can be useful e.g. when the tracker that generated it in the first place stops operating and we still need to keep track of the object.

A position report is associated with time. Either by *timestamping* it at the source or timestamping it when received. A *trail* for a given location item is an ordered list (by time) of reports within a given timespan. In a real-time view this means showing the movements of stations (as lines and points on the map) some minutes back in time, leading to the current position.

APRS infrastructure

APRS - Automatic Packet Reporting System (Bruninga, 2014) is based on GPS and AX.25 packet radio (Fox, 1984). It uses connectionless data packets to send position reports over radio. It operates on a single VHF channel and 1200 baud AFSK (Audio Frequency Shift Keying) modulation which is rather narrow band. The *APRS protocol* (Wade, 2000) defines several variants of position reports, compressed packets and timestamping of reports. It is not just for position tracking but also supports short text messages, telemetry, weather reports, etc. It was chosen for our tracking system since it is free to use, an open standard, is widely deployed in the radio amateur community and used on a daily basis. Devices that implement it are affordable, or not too hard to construct.

Figure 1 illustrates the architecture of the APRS infrastructure and how data flows from trackers to applications that can visualise the information. Data packets are broadcasted by mobile trackers and possibly retransmitted on air by digital repeaters (called “digipeaters”) to extend coverage. Internet gateways (“igates”), collect packets from radio and feeds them into a worldwide data stream on the internet. The coverage of repeaters or gateways depends on the topography, antenna height, etc. A range of 50 km is not unusual. The existing infrastructure can be extended by deploying mobile repeaters or gateways.

The APRS Internet service (APRS-IS) is a worldwide network of interconnected servers. Gateways (Igates) or in fact, any APRS application (controlled by a radio-amateur) can connect to the APRS-IS service in order to deliver data or to receive data. It is possible to specify filters when subscribing to the APRS-IS data stream, for instance based on location. Authentication and authorisation of users is not supported and data in transit is not encrypted.

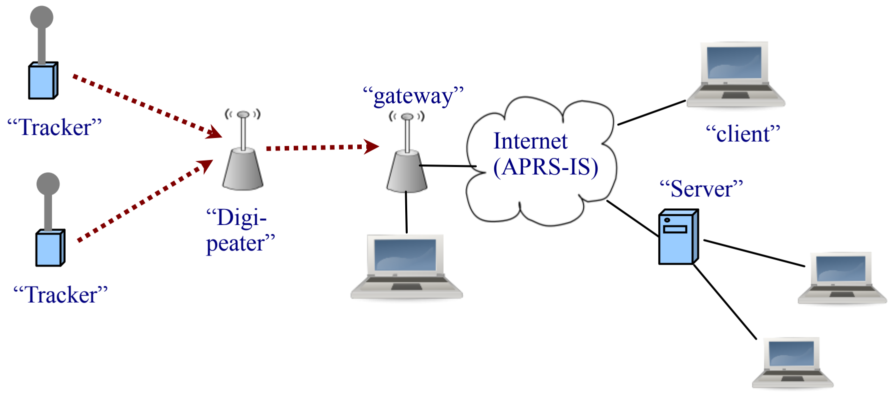

Figure 1. APRS infrastructure

Implementation

Developing a tracker

After some testing of APRS tracking in search and rescue exercises, the radio amateur group in Tromsø found that though some APRS trackers were available commercially, they were not quite suitable for the purpose at that time. Some were not complete in the sense that they needed external radios or GPS units, some lacked receivers to allow listening to the shared channel before transmitting, some were integrated into handheld communication radios but they were somewhat expensive, complicated to use and had limited battery capacity. Therefore the idea of designing our own tracking device from the ground up was born. A project was set up with the goal to construct a compact (handheld size) and affordable tracking device with at least the following traits:

- Complete, all-in-one unit with 4-5 watt transmitter, receiver, antenna, GPS, battery, etc..
- Handheld size and waterproof enclosure to allow portable use in different weather conditions.
- Easy and intuitive to use for non technical personnel.
- Moderate power consumption, integrated battery with at least 24 hours battery life in normal use.
- Open platform and open source software development.

The resulting device has been named *"Polaric Tracker"*. The user interface is one single push-button, three LEDs and a speaker for sound indications and a USB socket for configuration with a PC. The pushbutton is used for turning it on/off and to *generate APRS objects* to mark relevant findings. During operation it is hardly necessary to do more than that and to check that it functions.

The first prototype (proof-of concept) was tested in June 2008. The second prototype was a pilot series built in the time from November 2008 to February 2009. In this phase the components were mounted manually on the circuit boards. The number of malfunctioning boards was significant in this phase and important lessons were learnt. Figure 2 shows the prototype board. Already in the prototyping process, Polaric Trackers were used in real missions (see section 3) which gave us valuable experience and ideas. About 250 units have since been produced industrially and distributed (sold), mainly to radio-amateur groups around Norway. It has been considered to commercialize the device and recently, similar devices has been introduced to the market by Chinese manufacturers.

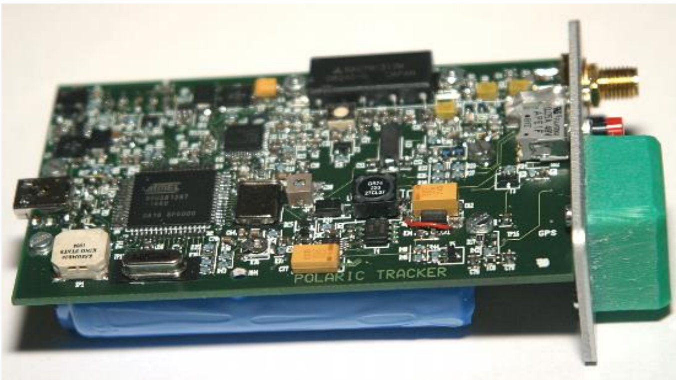

Figure 2. Prototype Tracker circuit board

Developing a map server application

Another important enabler for tracking in voluntary SAR is the development of a "map server" application called *Polaric Server*. The main purpose is to display position of objects on digital maps (based on received APRS reports) and update them in real time. Other important features include:

- The user interface is a web application. Users do not need to install more than a standard web browser. Alternatively it can be accessed via a smartphone app.

- Authorized users can, on the server, add information and manipulate how objects are displayed in a view shared by all users. For example choice of icons, use descriptive labels (annotations), hiding of unnecessary information, etc..
- To deal with information overload, servers can be set up with programmable filter views to configure what items is displayed as well as how the items are displayed. Users can select from a set of predefined filters.
- Uses a spatial database to store and retrieve dynamic and static data. The main purpose is to allow users to query search trails from the past, to display these on the map or export them to other analysis tools.

The application uses the free map-display service offered by the Norwegian Mapping Authority (Kartverket). In December 2009 the mapping authority started to offer web services (WMS) to the general public (for non-commercial use), to enable use of maps in various applications. Keeping our service open to the public is believed to encourage testing and development (of the APRS infrastructure) as well as recruitment of interested people to the radio-amateur and voluntary rescue communities.

The web-application is based on open source projects like *OpenLayers* (OpenLayers, 2015). The server software runs on a standard Linux/Apache/PHP platform. A separate back-end APRS server program processes (possibly multiple) dynamic input data-streams (APRS) and presents the information as XML markup to the front-end. The front-end can use map-layers (or other GIS layers) from external sources or a back-end which can do rendering, tiling or caching of static map-data.

The Polaric Server was developed as open source and it is clear that use of existing open source components as well as availability of public geographical data through external sources have made it possible to implement this application with reasonable voluntary effort. The application has been deployed in several instances. *aprs.no* is the official online tracking service by the Norwegian Radio Relay League (NRRL, 2015). The Norwegian Red Cross offers a similar service for their tracking system.

USE OF THE TRACKING SYSTEM

The tracking system described here has been used in a number of search and rescue operations, exercises, sports events, etc. In the Tromsø-area, it started in 2009 when the Polaric Tracker prototypes were made. The first big mission was to search for a missing fisherwoman near Vannøya in Karlsøy in Troms February 2009. It started with a air search (trackers placed in aircrafts). Thereafter it was decided to start a search along beaches and establish a base near the search area. Totally 11 trackers were placed on search teams from the Red Cross, Norwegian People's Aid, Civil Defence, and boats from the sea scout group. A mobile APRS repeater, a local internet gateway and map server was deployed in or near the command post. A video projector was used to display the operational picture (see figure 3 below).

This way of working has become a model for later operations where radio amateurs contribute with communication and tracking. The police (responsible for leading operations) and other organisations recognized the usefulness of tracking and since then it has been an established practice in Troms Police District to involve radio amateurs in this type of SAR operations. Since we offer an open online web-based service it is not unusual that the JRCC (Joint Rescue Coordination Centre) and LEMA (Local Emergency Management Authority) follow the operations using our web-interface.

The number of missions where tracking has been used increased in 2010 when trackers became available for other groups around the country. The system seems to work best when searching for missing persons over a larger area and where there is some time to organise. This is in many cases search for presumed dead persons which are difficult to find and these missions often last over several days. There are also examples of persons that have been lost in the mountains and needed help, search for missing people with dementia as well as search for suicidal persons; some of then have been rescued and helped in time thanks to quick response.

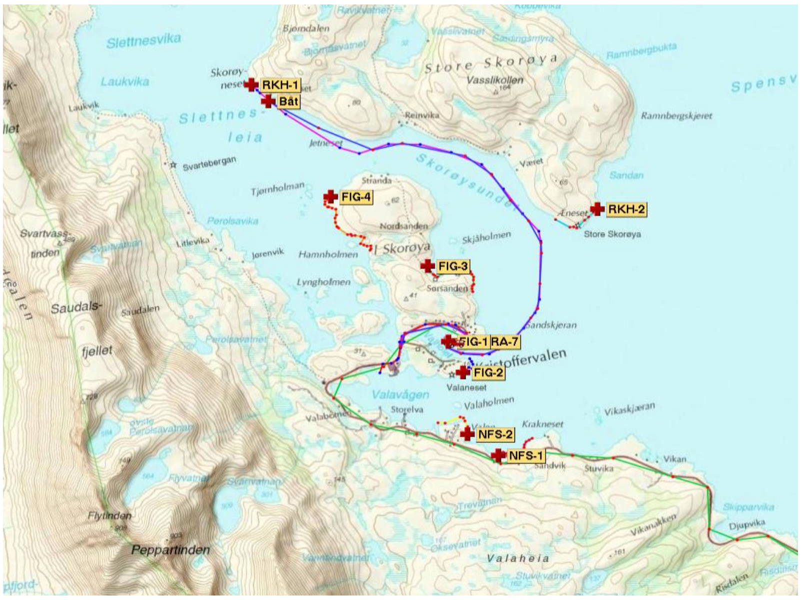

Figure 3. Operational picture of search, Vannøya, February 2009.

Figure 4 shows a map picture from a search for a missing person in Brøstadbotn in the northern Norway in 2010. The search was extensive and lasted for four days. Voluntary organisations, unorganised voluntary personnel, the civil defence and military forces participated in the search. The picture shows that an aircraft from the Norwegian Aero Club searches the area at the same time as other teams are searching on the ground. When the missing person was found, the search team immediately marked in the map picture by using the tracker to send an APRS object at the precise location.

Voluntary organisations have also been invited to contribute in larger national and international crisis exercises. Examples are Tyr 2010 (Jonassen and Rosø, 2011) and Barents Rescue 2013 (DSB, 2014) where tracking was used on Norwegian, Swedish, Finnish and Russian rescue units, boats and helicopters. In addition, tracking is popular is larger sports events, like e.g. marathon, ski or bicycle races. Such events are relevant training for voluntary personnel, especially when the event is spanning large distances it is useful to keep track of where the lead is, as well as where ambulances and other mobile support functions are located.

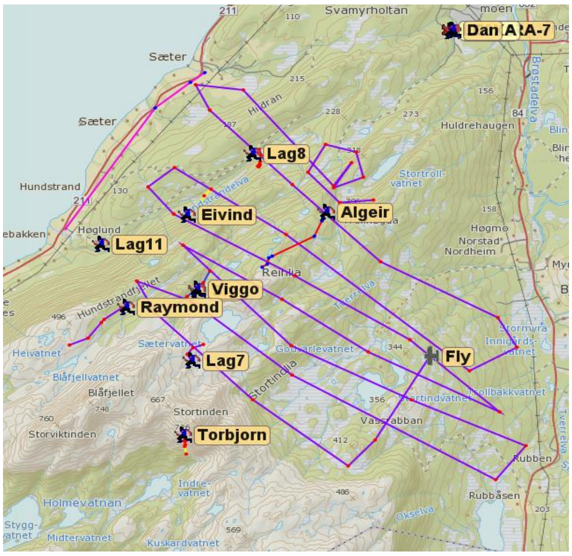

Figure 4. Operational picture of search, Brøstadbotn, 2010.

Historical data

The police authority leading such operations have several times asked for the possibility to retrieve historical tracking information to be able to document where searches have been performed. This was in an early phase improvised by using external APRS services that store data over some time. In 2012 a module for Polaric Server for storage and retrieval using a spatio-temporal database was made. Figure 5 below shows an example of a full day search (with 10 search teams) on the left side and one day search by an aircraft at the right side.

The ability to visualise data from such a database search is obviously useful in the planning of the next day in this type of situations since we see what areas have been searched. The police also emphasize the need to show to relatives of the missing person what has been done and where the search has been performed. It is also possible to download tracks from portable GPS devices into maps to document a search, but with this solution where data is collected and stored in a database in real-time we can do a historical search at any time during the operation.

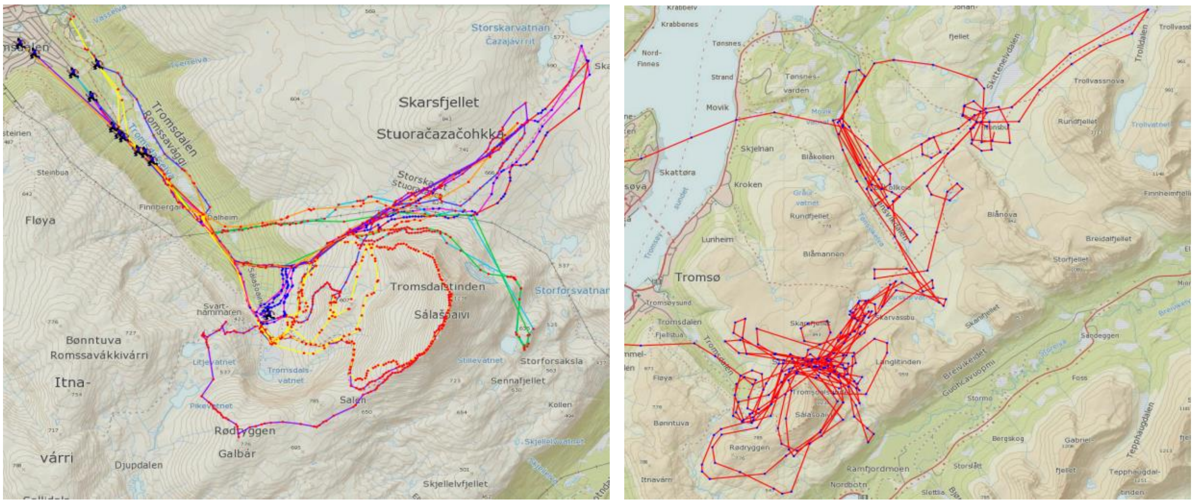

Figure 5. Tracks from a day of search near Tromsø in 2012.

Roles and tasks

Operating the tracking system can be seen as a specific role at the command and control centre (or command post). Tasks include keeping a record of where trackers are assigned, giving trackers meaningful labels and icons in the map, hiding unnecessary items, searching the database and presenting the relevant operation picture using a video-projector. The operator may also take care of other communication tasks or technical support. The annotation and editing task can if necessary be delegated to volunteers located elsewhere.

ANALYSIS

In this section we look a little closer into the issues of combining and refining data, as well as the requirement for mobility and offline operation. But first, the development process described here is mostly voluntary work and innovation is typically a result of participation in voluntary rescue services, radio-amateurs have for a long time contributed with communication support. Advanced ICT support is however a more recent contribution.

Some of the achievements in the project can be described as *innovation "under fire"* where ideas for improvement of the system come up during real actions or exercises where we helped out with tracking. Here, developers of the system could observe or participate and work with real data during actions to see what is needed.

Combining and refining data

The system presented here, collects positions from trackers and to presents them on a map, which is useful in search and rescue operations. A potential strength of a system like described here is the ability to combine data from a range of different sources. It can be:

- Static geographical data from authoritative public sources (typical GIS application data).
- Other public open data (mostly static) for example about weather conditions, road disruptions, web-cameras along the roads, information about hospitals, shelters, etc..
- Static geographical data produced by crowdsourcing. E.g. OpenStreetMap (Chilton, 2009)
- Data from different position tracking systems like AIS, smartphone apps, or various commercial systems.
- Data entered by the users of the system as the information is discovered, either directly to a web-application, via smartphone apps.

Annotating

An essential feature of the current system is the ability to manually *annotate* position data by the use of *aliases* (some other APRS tracking applications support so-called *tactical callsigns)*. A callsign that identifies a *tracker* is by itself not very informative and some meaning needs to be added. A single tracker may be assigned to different people, teams and vehicles over time, which again may be assigned to different *missions* over time. If the *label* on the map instead of the identity of the tracker, indicate who carries it and possibly its mission, it tells a lot more.

In the APRS protocol, each position report carries a *symbol tag* which is meant to indicate a *type* of vehicle or mission. This is used to select the icon to represent it on the map. However, it is impractical to update this in each tracker each time it is assigned to a new mission. Therefore we also allow the server operator to change the icon as well, for example to use a red cross icon when a tracker is assigned to a red cross team.

It better to enter this extra information into the server than letting each tracker send it. Trackers do not have alphanumeric keyboards and it is more efficient to assign the task to one person, possibly located outside the command post. Adding such information is currently being done manually. When a tracker is assigned to a team, it must be turned on, the operator must note who are to use the tracker, find the tracker on the map and add the descriptive tag and (possibly) change the icon. This process can be further improved by letting the operator enter information about missions when they are planned, along with starting and ending time. The system could use this information to automatically change the labels on the map as soon as the tracker-id is entered and the starting time is reached. Storing such information, linking trackers with their missions in a database, would also be useful in documenting and analysing the operation at a later time.

These observations indicate that we could benefit from doing further investigations on semantic annotation, which may be especially relevant when data from different sources are to be combined and linked. We could benefit from relating tracking information to conceptual models like (Dilo and Zlatanova, 2011) and look closer into ontologies and semantic technology (Fan and Zlatanova, 2010; Mobasheri, Oosterom, Zlatanova and Bakillah, 2013).

Sensitivity of combined information

Obviously, it can be problematic to openly publish a full operational or tactical picture on the internet in real time. Combining data from different sources, each which is open, and in particular, annotating position data from trackers (like described above) may make the total picture sensitive, since it may make it easy to identify what is going on and *who* is carrying out the missions. If the full picture is to be made available for non-authorised personnel, one should at least be careful about publishing the identity of the persons carrying trackers.

It may sound strange that this information is being public in the first place, but keep in mind that our tracking system is primarily aimed at volunteers and is continuously being tested and developed by enthusiasts. Furthermore, the radio-amateur APRS data stream is broadcasted over radio and streamed over the internet in clear text (encrypting HAM radio transmissions is not legal) and our system was initially designed as a generic APRS data viewer. Therefore, all information was initially made visible for interested people without authorisation. When this system is being used emergency situations and when annotations and other, not-so-open data sources are included, there is a obvious need for hiding the operational picture from the general public.

A change was made after journalists were showed the display during a search for a missing person close to the city centre of Tromsø, and soon after, a picture of the map as well as a web-link to the map-server were published in online newspapers. We were afraid that the server would be overloaded and SAR personnel could be disturbed if their positions were published in real-time. The newspapers were asked to remove the snapshots and the link, but they just removed the link. After this incident, we added an ability to hide some information from non-authorised viewers. We also published some terms of service that apply to all users.

Mobility and connectivity

Though the internet is useful for communication and information gathering during emergencies, the internet or fixed communication networks may in some situations be unavailable or may be unreliable or low bandwidth. A command post may be established on a site without a proper broadband connection. Furthermore, in the case of larger incidents, the public communication infrastructure may be affected. Therefore we should plan for the possibility of having a weak connectivity or even none at all and be able to use alternative communication channels like e.g. amateur radio bands.

With our tracking infrastructure it is possible for a tracker to communicate directly with a Polaric Server instance or via APRS repeaters. The Polaric Server can run on a local area network with no or limited connectivity to the internet. This has been tested and there are some challenges and possibilities that could be investigated further.

Even if the APRS network can cover areas not normally covered by e.g. cellular networks, it cannot easily cover all areas. The fixed APRS infrastructure can however easily be extended with mobile repeaters to cover remote areas of interest. It may be challenging to provide good coverage and planning the infrastructure must be done with some care since the capacity of the channel is reduced as the number of repeaters increase. Since there may be multiple active servers, also at mobile command posts, we have developed a simple Peer-to-Peer protocol to synchronise annotations etc. amongst server-instances, based on the short message capability of the APRS protocol.

There is a need for caching and prefetching map tiles and to ensure that they are available when and where they are needed. This has been somewhat challenging due to legal restrictions on collecting and storing map data in an early phase of the project. There are still restrictions on how many map tiles that can be downloaded within a time frame.

An information system for emergency use should be able to make use of available communication channels and adapt to changes in connectivity. Adaptability and quality of service management is a possible topic for further work. I could be useful to define different modes of operation and their resource/connectivity requirements.

DISCUSSION

The approach described here has some strengths and weaknesses. It is low cost, it is based on voluntary work, open source software and open public data. Since it is used and tested by enthusiasts on a daily basis, there is a high probability that problems are discovered and fixed quickly. It is easily accessible by first responders at the command post if the internet is available. If not, a LAN with a local server can be established, another APRS client program with appropriate radio equipment can be used. Coverage can be extended to remote areas using mobile equipment and the system can be operated remotely. However, the system is complex and its main operators should have sufficient technical knowledge. Therefore some organisation and education is necessary. The system is vulnerable since it depend on the time, enthusiasm and knowledge of very few volunteers to develop and run it.

The system depends on the availability of open public data, most importantly to map data through web. Not all countries allow such access to map data to the general public and Norway started opening up Web Map Services (WMS) in 2009. There are still public materials like orthophotos that could be very useful but we are not allowed to use it in our application. Free or commercial alternatives like OpenStreetMap or Google Maps do not provide sufficient detail in remote areas though valuable in more populated areas.

In our experience the *precision* of tracking points from cheap GPS units is acceptable in the spatial dimensions. Usually within a few meters. The problem is however with the *temporal* dimension. An APRS channel has a very limited capacity since it is narrow band and shared among many devices. Furthermore, transmissions may be lost due to weak signals, collisions, etc. Trackers implement an adaptive algorithm to decide when to send, that takes speed and direction changes into consideration. It transmits more frequently when moving quickly (typically 10 or 20 seconds between transmissions) and less frequently if moving slowly. We have experimented on piggybacking previous reports on current packets to add redundancy and achieve a slightly higher resolution in the temporal dimension after some delay.

Coverage in remote areas can be better than with tracking systems using the cellular networks at the cost of lower bandwidth. We have experimented with using a smartphone app as a tracker which would be an alternative in urban areas, but we need to be aware of the drain on the battery. Using a satellite based tracking system could offer better coverage in remote areas, but is expensive and may offer even less bandwidth.

CONCLUSIONS AND OUTLOOK

This paper describes how volunteers in Norway, especially radio-amateurs, have contributed to land search and rescue services by providing GPS tracking of search personnel, vehicles, etc. The main motivation has been safety for the rescue personnel but the use of tracking has also been useful in monitoring, coordination, analysis and tactical planning as well. GPS tracking and GIS applications is not a new invention, APRS is a not a perfect technology and the infrastructure is not optimal, but it works and have been used by amateurs for more than a decade.

Tracking is useful in some types of operations, especially searches for missing persons in larger areas and where many different resources are involved like search teams, boats, aircrafts, cars, snowmobiles, etc. In larger crisis management exercises it has just been one part of a larger system and used in certain scenarios, typically those involving search and rescue.

There are many cases for further research and development. In general tracking is part of the information system used to support operational and tactical decisions. We envisage the integration of a larger set of different data sources, crowdsourcing, and interoperability between different systems. To better support this we can look closer into data models for SAR use, semantic annotation, etc. There is also a case for making information systems that better can adapt to varying connectivity, or varying quality of data (e.g. reliability), for example by assessing the quality of combined data presented and informing the user what he/she can expect.

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