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DYNAMIC EVACUATION ARCHITECTURE USING CONTEXT-AWARE POLICY MANAGEMENT

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In recent years, there is an increasing number of communication systems and intelligent tools supporting first responders and evacuees in the tasks of communication, decision-making, information exchange and coordination in emergency and crisis evacuation.

This paper gives the state-of-the art of communication technologies for crisis and emergency evacuation and identifies challenges for usage of policies for intelligent information delivery, (re)configuration of communication services, sophisticated evacuation path distribution and automated control of the communication services of the evacuation systems.

Enhancements of the emergency communication infrastructure based on intelligent context-aware policy management solutions are discussed considering emergency scenarios in building environments and groups of first responders and evacuees.

Design of intelligent policy management facilities for crisis and emergency scenarios are discussed considering enhancements of ontology based autonomous policy management prototype.

Keywords: context; emergency; crisis; building evacuation; first responders; evacuees; time-critical information; communication infrastructure; policy management; context-aware policy.

1. Introduction

Today, there are different efforts for development of robust and efficient communication infrastructure for crisis and emergency situations. Examples are:

- Integration of sensor network architectures (protocols and sensor data processing tools) allowing increased situation awareness and intelligent control based on sensor measurements and evaluation of sensor data [MMQM 08];
- Management, simulation, scheduling and planning (forecasting) of critical communication resources, for instance bandwidth and energy of communication considering spatial and temporal dimensions [NT 05], [BA 02];

- Routing protocols considering alternative routing based on wireless mesh networks infrastructures and network integration (broadcast, wireless, sensor, cable) [MWG 07];
- Information processing algorithms that exploit available information from different sources, provide fusion of information, as well as process signals based on patterns (heuristics) to support decision making, information management and coordination [Bern 08];
- Intelligent technological solutions based on distributed problem solving, social intelligence, intelligent training systems, intelligent agents and agent based systems, intelligent web based applications, cognitive systems, machine learning, knowledge representation and other techniques;
- Security and information assurance, automatic negotiation of trust and identity management [KT 08];

Recently the integration and practical deployment of techniques based on artificial intelligence, cognitive science and knowledge based processing has gained increasing importance. For example in the fire accident at Düsseldorf airport 13 people died going into the wrong direction, because of wrong evacuation information. Such mistakes could be avoided by using intelligent communication infrastructures, which:

- Process data of different sensors integrated in the building (window/door/fire),
- Include procedures for intelligent evacuation decisions considering different information sources and related ontologies,
- Produce evacuation plans considering spatio-temporal relationships, sophisticated identity management (grouping of actors, coalitions) and context dependent evacuation and communication (QoS) policies.

An autonomic context-aware policy management is a further component, which can enable intelligent communication infrastructures for crisis and emergency management.

Based on the current prototypes for adaptive and ontology based policy management developed in the EU project NETQOS [NETQOS], [MWG 07], [MWNH 08], this paper discusses enhancements of the intelligence of the policy management systems for support of context-aware communication for crisis and emergency evacuation.

In section 2, achievements in intelligent communication infrastructures with special focus on policy management for emergency evacuation are discussed. Section 3 demonstrates examples for context aware policies with special focus on building emergency evacuation scenarios. Section 4 discusses intelligent policy management interfaces for emergency evacuation communication infrastructures. Section 5 concludes this paper.

2. Overview of intelligent communication support for emergency

The usage of intelligent information processing technologies to support collaborative work, enhanced situation awareness and distributed decision making of first responders and evacuees are important concepts of today’s efforts in emergency management, focused on building of communication infrastructures for emergency (disaster) scenarios.

For instance the European project WORKPAD is aimed at designing and developing an innovative software infrastructure (software, models, services, etc.) for supporting collaborative work of human operators in emergency/disaster scenarios [WORKPAD]. In such scenarios, different teams, belonging to different organizations, need to collaborate with one other to reach a common goal; each team member is equipped with handheld devices (PDAs) and communication technologies, and should perform specific tasks.

The architecture considers information services for crisis and emergency based on *building of communities*:

- A back-end peer-to-peer community, providing advanced services, data & knowledge & content integration, and
- A set of front-end peer-to-peer communities, that provide services to human workers, mainly by adaptively enacting processes on mobile ad-hoc networks.

Further approaches for information delivery and data mining in case of emergency and crisis are based on pervasive environments [CLMM 08].

Advances in distributed architecture for Pervasively Shared Situational Awareness and integration of sensor technologies allow improved evacuation support. For instance, the “Ancile” architecture initially developed to satisfy the needs of tracking personnel (soldiers) and notifying them of events of interest in their vicinity was enhanced for emergency response personnel in times of crisis [MMQM 08].

Automated networked systems can be designed to support the distributed coordination of first responders for scenarios, in which groups of evacuees seek shelter during a crisis considering constraints, such as capacity, medical requirements, capabilities and location [KSLNDMR 08]. Further focus is the Dynamic Network Reconstruction in case of destroyed emergency communication infrastructure [ATS 04].

Diverse activities to facilitate consensus building in the area of public safety communication and information management systems are leading to the establishment of organizational structures, e.g. the “Forum for Public Safety Communication Europe” [Forum].

One aspect of the decision support systems for emergency management and evacuation is planning and determination of optimal network configuration, routing between different actors and groups and service access. For this purpose, tools and algorithms are proposed based on artificial intelligence, mathematical modeling and operation research. Their objective is to produce evacuation plans that identify routes and schedules to evacuate affected actors (groups) to safety when disaster happens in buildings.

The simulation approaches are based on construction of evacuation nets in buildings and execution of their simulations as practical supporting level. An example is simulation of evacuation scenarios of buildings using Petri Nets [NT 05]. The current methods of evacuation planning can be divided into two categories:

- Traffic assignment-simulation approach using simulation tools, such as DYNASMART [MSZ 04] and DynaMIT [BA 02] to conduct stochastic simulation of traffic movements based on origin-destination traffic demands

- Route-schedule planning approach using network flow and routing algorithms to produce origin-destination routes and schedules of evacuees on each route, as for instance NETFLO [KH 80] and EVACNET [KFN 98]

[LGS] presents a heuristic algorithm, called Capacity Constrained Route Planner (CCRP), which produces sub-optimal solution for the evacuation planning problem. CCRP models capacity as a time series and uses a capacity constrained routing approach to incorporate route capacity constraints. It addresses the limitations of linear programming approach by using only the original evacuation network and it does not require prior knowledge of evacuation time.

Graph-theoretical approaches to model and plan evacuation are found in different studies. For instance, [SK 06] proposes an algorithm to find a contraflow network configuration, i.e. the ideal direction for each edge, to minimize evacuation time, in case that a transportation network is given having source nodes with evacuees and destination nodes as responders.

Contraflow is considered a potential remedy to reduce congestion during evacuations in the context of homeland security and natural disasters (e.g. hurricanes). This problem is computationally challenging because of the very large search space and the expensive calculation of evacuation time. Further modeling approaches are based on learning, extraction and routing of relevant dialogue information, which is useful for particular responders / evacuees involved in the emergency evacuation scenarios [NSom 08]. Identification of emergency tasks, as well as dynamic knowledge sharing and integration between emergency tasks is an important concept of emergency systems [Bern 08].

Several modeling environments exist for the simulation of large-scale evacuations of buildings, ships, or other enclosed spaces. Example is the prediction and mitigation of crush conditions in emergency evacuation [HAG 08].

Besides the modeling algorithms for planning of evacuation, routing data mining and information delivery, newer proposals are aimed to focus on operational requirements concerning access control, policy and identity management in crisis situations. In this context, [SGB 08] discusses context-aware adaptation of access control policies for crisis scenarios. The spatio-temporal policy and identity management is an important issue of crisis communication infrastructures. Particular facilities are studied in the EU IST project ORCHESTRA, i.e. “Open Architecture and Spatial Data Infrastructure for Risk Management” [ORCHESTRA].

An example for enhanced policy management in crisis situation is to give responders access to additional information in emergency locations enhancing their normal operating environments. Policy management for crisis scenarios can include state dependent and spatio-temporal policies, as it is proposed in the current research [BDBB 08].

Policies for emergency situations can control the selection of alternative routes in dynamic adaptable communication infrastructures, for instance wireless meshes. Communication policies for emergency applications can be designed to consider different infrastructures. In case that the usually used infrastructure has been destroyed, mobile ad-hoc infrastructures can be dynamically configured [ZWJ 08].

Further research focus is the context aware policy management, which is discussed in our paper, considering autonomic policy management facilities [MWG 07].

3. Policy and identity management of communication infrastructures for first responders and evacuees

Challenges for context-aware policy management of communication infrastructures for first responders and evacuees are shown considering two scenarios:

- In the first scenario, the usage of spatio-temporal adaptation of access rights and policies of the front end groups of the first responders for provisioning of situational awareness in case of crisis is shown.
- The second scenario describes autonomic adaptation of routing policies of different evacuees groups in the building impacted by the fire considering location information and spatio-temporal relationships.

The two scenarios assume sensor information providing knowledge of the fire location and its impact on the building environment.

3.1. *Policy aware first responder's communication*

In our scenarios, the communication infrastructure is designed to enable communication for different groups of responders and communication subsystems. An example for interaction of different communication infrastructure inside the first responders is outlined in figure 1.

The main tasks of these groups are:

- C&C (Command and Control) center, which is based on the fixed back end infrastructure at the fire brigade headquarters. It usually involves high speed and high bandwidth connections to support complex simulation and modeling required for decisions making in crisis and emergency scenarios.
- Distributed mobile C&C stations (MCCS) in the fire fighter vehicle, which are able to coordinate the front end fire brigade groups and individuals based on interactions with the back end infrastructure and front end fire brigade using wireless mesh networks and mobile Internet access infrastructures.
- Front end fire brigade groups, which are supported by flexible and dynamic wireless mesh communication infrastructures allowing the access to MCCS and assigned evacuees groups using different routes.

Context aware policy management facilities depend on the particular tasks of the front-end and back end staff.

In order to support robust communication, dependent on the spatio-temporal position of *the front end fire brigade* and rescuers, the context-aware crisis policy management can adapt the delivered services and information, as well as the resource access of the concrete fire brigade. So for instance, the policies can impact:

- Reception of sensor information and status reports from the target building, i.e. which information is delivered to the particular fire brigade group;

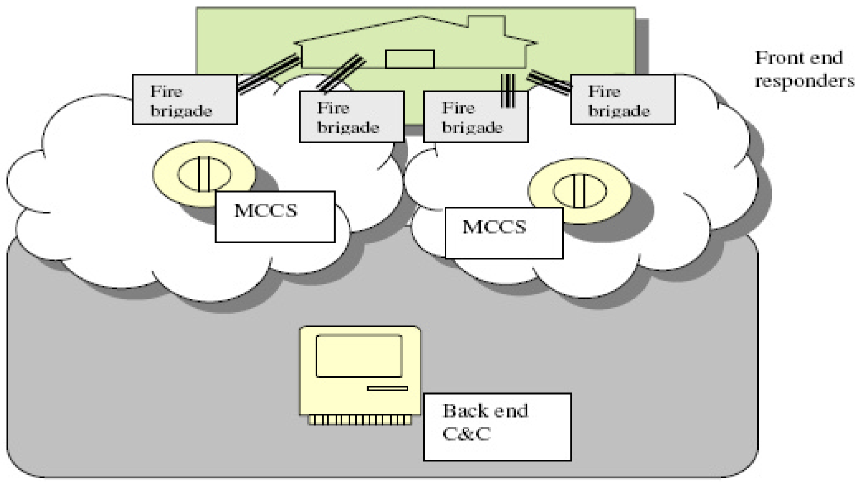

Fig. 1: First responder communication infrastructure involving different groups

- The delivery of images from cameras, individuals and devices inside the building dependent on the location.

Concerning *MCCS front end staff* in the scope of the target buildings, the policy management can autonomously extend the MCCS services to enable:

- Reception of detailed electronic floor plans of the target premises including information about all attached devices
- Control of specific devices and routing connections connected to the system inside the building. For instance, the rescue stuff may send some configuration information to the evacuees devices
- Request of dynamic information to evaluate the fire scope in the floor plans (for instance, sensor history to be able to understand the dynamic of the emergency),
- Access to system security facilities.

In the two cases of front end responders (MCCS and fire brigade), policies are used for filtering of information and services, as well as for enhancement / restriction of access rights. Using policies for acquisition of information about the emergency situation, following models can be produced in cooperation of front end and back end responders:

- Spatial model: This model consists of the static information about the building: Building Information model [ETSL 08];
- Threat model: The threat model describes different kinds of threats to humans, like fire, water, gas, etc. as well as the time of their occurrence (before, during and after evacuation), their likelihood, and their consequences (injuries, up to death);
- User model: This model describes user specific characteristics, e.g. mobility (wheel chaired persons need different evacuation paths than others), etc.

In interaction with identity management facilities, context-aware policies can be defined for different responder types and groups of responders. So for instance, dependent on the location and assignment of evacuees, Red Cross responders and fire brigades can be put together to a joint first responder identity group, able to get specific information about evacuees.

3.2. *Context aware policy management for evacuees*

Automatic information exchange supported by policies seems to be a viable approach for knowledge acquisition by the evacuees about optimal escape (evacuation) routes and optimization of their networking connections to get time-critical information [HS 07]. We consider two main policy types for support of evacuees in emergency situations:

- Policies aimed to select dynamically optimal evacuation paths using learning algorithms;
- Network communication policies for evacuees' support focused on establishment and keeping of network connections to evacuees' devices (mobile phones) and on communication service delivery in timely, secure and reliable manner, e.g. delivery of evacuation path descriptions.

The scientific challenge for appropriate policy provisioning *for optimizing evacuation paths* is the extraction of information about the current situation of evacuation paths ("situation awareness") considering environment conditions collected by sensors (e.g. fire or temperature sensors), maps and other context means.

This means, the context learning and processing system has not only to evaluate the collected context information in a statistical manner (e.g. mean value of temperature), but has to evaluate the collected information intelligently and derive added value from the collection (e.g. a geo-located distribution of temperature sensors may be interpreted in a way, that dangerous regions can be identified and evacuation support avoids the usage of paths crossing these regions).

By using appropriate learning algorithms (for instance based on reinforcement learning), the quality of the alternative evacuation paths can be dynamically evaluated by the policy management system and the optimal evacuation path for the evacuees can be selected.

The basic algorithm for evacuation path calculation can be based on Dijkstra Algorithm, which finds the shortest paths in a network using a cost matrix (a building plan is represented by a graph with nodes and links, "costs" are associated with all links). Possible cost factors include length, capacity, and environmental conditions (like presence of obstacles, gas, high temperatures etc.).

The selection of the cost factors is crucial for the selection of optimal evacuation paths. Whereas length and capacity are static information which can be derived from building plans, the values of the further cost factors (gas presence, temperature, etc.) have to be collected in time *during* the emergency case, as they are highly dynamic and unpredictable. The devices of individuals moving through different parts of the building can offer valuable live data for evacuation. In combination with indoor localization methods, effects like congestion can easily be monitored and used for better path decisions [SK 06].

Further kind of evacuees policies are the *network policies dealing with establishment, Quality of Service (QoS) and delivery of services to the devices of the evacuees*. The network policies control:

- Communication services between and within the evacuation groups (intra- and inter evacuation community communication);
- Communication between rescue staff and evacuees.

The data collected by the evacuees (resp. their devices) is transferred to the rescue staff in order to inform the responsible persons about the emergency system's knowledge. For instance, the knowledge of the spatial distribution of evacuees does not only affect the system's evacuation path calculation, it is also important for the rescue staff which has to prioritize its rescue operations.

An important aspect of the policy design is the question: Who has access to which information? This depends on the roles of the individuals in the emergency scenario:

- The rescue staff can be subdivided into officer in charge, other officers in the field, supporting staff (e.g. technicians), officers in the headquarter, etc.
- Evacuees may be grouped e.g. regarding their location (how risky is their current environment), or regarding their physical fitness (e.g. mobility impaired or not), or regarding their "normal" role in the building (e.g. a facility manager may have more relevant knowledge than a visitor).

4. Context-aware policy management system for emergency applications

Different kinds of policies for emergency evacuation applications involving groups of responders and evacuees have been discussed in the previous sections. The focus now is the specification of these policies using autonomic policy management and ontology tools, as well as their intelligent provisioning.

4.1. *Introduction to context aware autonomous policy management*

Context aware policy management deals with specification of policies of the different actors (responders, evacuees) and their enforcement based on the specified context [USPat 06]. The policy context describes information concerning responders and evacuees. It can include: location and access network, sensor information, monitoring data, cost requirements, information delivery subscriptions, advertising services, end systems and devices for the delivery of the service (application) and requested delivery time for time critical applications.

Based on reasoning and modeling of context, the services delivered to the responder groups and evacuees can be customized using policy definitions.

The context aware policy enforcement is usually required in mobile communication infrastructures [MMK 06], but the specific characteristics of emergency applications, for instance assignment of evacuation paths to evacuees with different locations using fixed networks, requires considering also fixed network infrastructures and sensor networks.

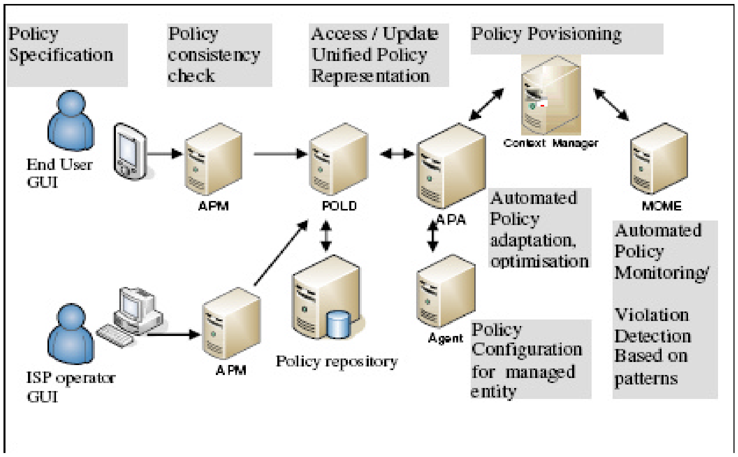

Fig. 2: NETQoS actor based QoS policy management - interaction of components

Context data can be related to the identities of the responders and evacuees and can be used for determination of evacuation paths, information delivery and network usage. Thereby, the context depends on the application; it can be described by ontologies.
Context aware policies can be used for different scenarios in emergency applications, as for instance using ambient networks [Mou 08] and pervasive computing systems [KT 08]. Collecting the context data for emergency applications is a complex task, which can involve the usage of context broker architectures [Aly 07].

4.2. *Components of NETQOS policy management architecture*

The NETQOS architecture is aimed to automate the QoS policy specification and the automated provisioning of policies considering policy requirements of different actors [NETQOS], [MWG 07], [MWNH 08].

In the NETQOS policy framework, actors can specify / change their own policies dynamically using appropriate ontology based interfaces. Dependency and consistency checks as well as business policy transformations in operational policies are supported by semantic relationships specified by the ontology [MWG 07].

The NETQOS system includes components for dynamic specification of business policies, ontology based policy translation and storage of unified policy representation in a common repository, automated configuration of policies at network and transport entities, policy monitoring, policy violation detection and operational policy adaptation. The NETQOS components interact based on the policy repository including unified policy specifications of different actors. Figure 2 shows the main functions of the NETQOS components:

- Actor Preference Manager (APM) used for dynamic definition and translation of business level QoS policies;
- Ontology and actor oriented GUIs for policy specification and administration;

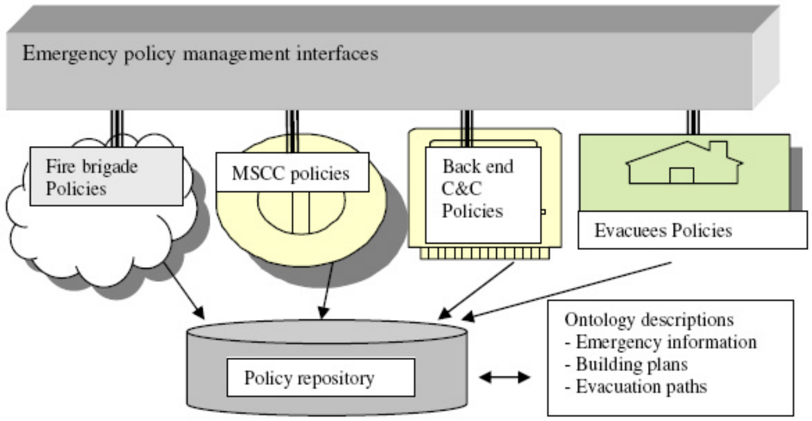

Fig. 3: Policy management interfaces and repository for emergency applications

- Policy Description and Management (POLD) supporting translation, access, change and storage of unified policies;
- Automated Policy Adapter (APA) deciding on efficient mappings of the unified policies of the repository into operational policies based on measurement and monitoring information;
- Context Manager – an event manager, controlling interactions between different components;
- Monitoring and Measurement tool (MoMe) for policy monitoring based on measurement requirements and policy violation detection;
- Agents: NetAgent responsible for automated policy configuration at network entities, TransportAgent responsible for automated policy configuration at transport entities.

4.3. *Policy management interfaces for emergency control specification*

Autonomous policy systems like NETQOS can reason, monitor, learn and act intelligently based on predefined policies and integrated intelligence [MWNH 08]. Autonomous components perform tasks intelligently adapting and automatically enforcing policies defined by specific actors without the need for human intervention. Such intelligent systems have the potential to support the tasks for information and evacuation plan delivery automatically using appropriate policies dependent on the context.

In order to support emergency evacuation considering policies and their autonomous processing, policy management interfaces for emergency evacuation can be designed and integrated considering available autonomous policy management systems, like NETQOS. The benefit of the extension of available autonomic system with emergency functions is that functions and data bases can be used without duplication by the emergency applications.

As shown in figure 3, policy management interfaces can be used together with ontology descriptions and policy repository to control the information delivery to the different groups of responders and evacuees.

5. Conclusion

The aim of the proposed architecture is to support first responder emergency forces. This will be validated by a trial. The proposed extension of the intelligent policy management in NETQOS will support robust and adaptable information management and decision support, leading to an increased level of safety for the first responders and the evacuees. The main benefits are:

- Open communication infrastructures and unified policy repositories will be the base for future emergency applications, as they allow cooperation between different kinds of responders and evacuees.
- The generic design and the usage of ontologies allow the usage of user specific information flows (e.g. evacuation paths for wheel chaired persons).
- The policy context description may include information about location, access networks, sensor information, monitoring data, cost requirements, etc.

Further work is aimed at integration of identity management functions in emergency scenarios, i.e. identity enabled policy management for emergency applications [MWNH 08]. By applying appropriate AAA (authentication, authorization, and accounting) technologies to determine the access rights for responders / evacuees the trustworthiness of the delivered information can be guaranteed.

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