

Trust for Location-based Authorisation

Andreas U. Schmidt*,

Nicolai Kuntze*, Jörg Abendroth†,

*Fraunhofer Institute for Secure Information Technology SIT

Rheinstraße 75, 64295 Darmstadt, Germany

Email: {andreas.schmidt,nicolai.kuntze}@sit.fraunhofer.de

†Nokia Siemens Networks GmbH & Co. KG

Otto-Hahn-Ring 6, 81737 Munich, Germany

Email: joerg.abendroth@nsn.com

Abstract—We propose a concept for authorisation using the location of a mobile device and the enforcement of location-based policies. Mobile devices enhanced by Trusted Computing capabilities operate an autonomous and secure location trigger and policy enforcement entity. Location determination is two-tiered, integrating cell-based triggering at handover with precision location measurement by the device.

I. INTRODUCTION

Ambient technologies propose to enrich the mobile environment with different computer devices and networks. One use case is to utilise a user device for remote control of other systems — to automatically turn on the light when entering a room, or to enable access to the emergency controls of a power plant while repairing the pipes. Often, a natural requirement is to restrict possibilities to authorised personnel in a certain location. Vice versa sometimes one wants to restrict the functionality of devices based on its location, e.g., disable the camera while entering a sensitive area. All these scenarios require location based authorisation and sometimes access control, a subject which has attracted some attention in the literature, cf. [1] and references therein.

The implementation of location based authorisation can be based on various methods for location determination, e.g., triangulation (e.g. strength of the device signal at six base stations [2], [3]), calculating the round trip time [4], or deploying a GPS module locally to the client. The first method lacks the precision, and the second requires new sensors to be installed in the location-based authorisation enabled areas. The last has not been deployed because relying on the client side for location information is deemed insecure. Event though hybrid approaches like combination of triangulation and GPS exist, the latter argument applies to them. In conclusion current approaches are generally unfit for authorisation and access control based on location with scalable strength of enforcement. We propose a solution, that combines three technologies. First a network-side location trigger, which only has cell granularity, and second a device-side enforcing agent using de-central (e.g. GPS) or co-operative (e.g. A-GPS) location methods and concurrently enforces the pertinent policies. Third security is established by applying Trusted Computing concepts of Attestation. Section II presents the proposed concept on the level of functional building blocks,

architecture, and operational scenario. Section III defines the required communication protocols and their integration into pcs networks. Security and efficiency of the concept and application scenarios are discussed in Section IV. Section V concludes the paper.

II. TLTA CONCEPT

In order to fell authorisation decisions based on device location, an entity called *location trigger* must have access to location information and be able to provide this information to other entities enforcing according policies, either on the device or on the part of some service. The concept of an Trusted Location Trigger Authorisation (TLTA) we propose in the following, rests on these key ideas. First, the location trigger in TLTA operates on two separate levels: i) Handover-based localisation within a network cell and ii) GPS-based (here always meaning either full, device operated GPS or A-GPS) localisation within an area circumscribed by a perimeter of cells. Second, a trusted entity on the device, called the Location Trigger Enforcer (LTE), embodying the location trigger functionality and enforcing, possibly in co-operation with a network-side counterpart, authorisation policies. The trust in the LTE rests on security properties of the device, which we assume to be a trusted computing (TC) platform for the purpose of location-based authorisation. The latter notion is, for our subject, specified by the standards of the Trusted Computing Group's (TCG) Mobile Phone Working Group (MPWG, see [5]). The necessary architectural principals of the MPWG for TLTA are explained in Section II-B. It should be noted however, that the TLTA concept is applicable resting on any other trusted platform architecture which fulfils the core requirements in the namely section.

In the following, we will take an agnostic stance with respect to the actual restrictions that are to be enforced and just speak of 'the policies' to be enforced. The next subsection sketches the architecture of a TLTA system and security-relevant assumptions. The state sequence of a device operating under the TLTA scheme is developed in Section II-C.

A. Entities and their functions

We here choose the Long Term Evolution of 3G Networks specified by the 3GPP standardisation (3GPPLTE, see [6]) as

the technical framework for the presentation of TLTA. Within it, various improvements over common 2G and 3G network architectures are specified. One of the aims is to simplify the overall architecture. This flat, all-IP based infrastructure is referred to as System Architecture Evolution (SAE). Meeting technical and performance requirements arising from an analysis of the current state of mobile technology resulted in a reduction of the number of network nodes involved in data processing and transport. A flatter network architecture leads to improved data latency (the transmission delay between the transmitter sending data and the time of reception) and better support of delay-sensitive, interactive and real-time communications.

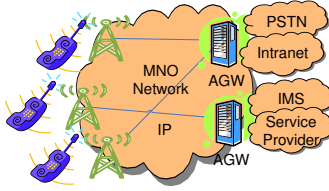


Fig. 1. SAE model and its basic components

The SAE model is shown in Figure 1 and consists of two types of network elements. Access of user devices, called Mobile Terminals (MT) is facilitated by enhanced base stations, referred to as enhanced Node-Bs (eNB). They provide the air interface and performs the resource management thereof. The second class of elements are the Access Gate Ways (AGW) which implement management functionalities and act as data gateways for user packages. The AGW establishes connections to Service Providers. Within this core network model the MNO can offer different services, for instance A-GPS.

Figure 2 depicts the interaction between the basic SAE architecture (shown as an MNO cloud) and the components added by TLTA. The customer who requests the enforcement of certain policies on devices in a geographic area, called the *protected zone*, is termed TLTA service requester (TLTSR). The TLTSR handles for instance the provisioning of content to devices. TLTA introduces on network operator side the Trusted Location Trigger Authorisation Centre (TLTAC) which establishes a pre-defined geographic area within the area covered by the MNO network. The TLTAC receives (i) the physical geometry of the protected zone and (ii) the desired policies to be enforced within this zone (A in the figure). Based on these data the TLTAC determines configures certain eNBs of the MNO in Step B. After the setup TLTAC's main task is to authenticate the end users devices and to maintain a list of them for authorisation purposes.

A Location Trigger Enforcer (LTE) is integrated in the end users MT which is the device-side counterpart of the TLTAC (The abbreviation LTE used in this paper should not be confounded with Long Term Evolution in the context of the 3GPP). LTE (i) receives and holds the policies from TLTAC, (ii) receives and holds the protection zone geometry, (iii) determines entry and exit events to the protection zone by

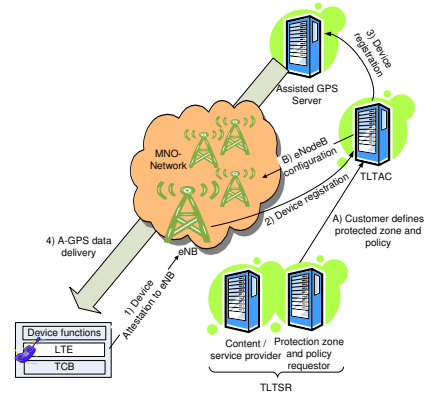


Fig. 2. Interaction of an existing MNO network and the TLTA components

some high-precision location mechanism, e.g., A-GPS, and (iv) enforces the policies on the device.

After this setup, MTs entering the protected zone may acquire certain services. The access to these services is controlled by the LTE. The basic scheme is that the device which enters the protected zone performs an attestation (see below) of its internal state and configuration to the MNO (Step 1 in Figure 2). If this attestation succeeds the device is registered at the TLTAC (Step 2) and also registered with the A-GPS service, or any other location providing service which is used to determine the accurate location of the device (Step 3). These registration steps are mainly required to protect the location service against fraud and to enable certain payment methods and schemes.

B. Trusted MTs

The TLTAC and LTE together form a Policy Decision Point (PDP) / Policy Enforcement Point (PEP) related model based on a local enforcement of policies. From the perspective of the content provider the trustworthiness of the local LTE must be testified and sufficiently strong. Therefore, TLTA requires that the MT constitutes a trusted platform resting on certain capabilities constituting a Trusted Computing Base (TCB), which for the purpose of this report comprise:

1) *Secure boot*: The boot process is the time span from the power on to the stage when the user is able to interact with the device. Within this time span, secure boot ensures that fundamental capabilities are in place which are critical for the reliability of the system, comprising in particular means for resource isolation and management. During secure boot, as defined in [5], each component is measured in order of execution. These measurement values are then verified by a local verification agent using so called Reference Integrity Measurement (RIM) digital certificates. If the values match then the processing continues and the started component is registered in a log as well as in a corresponding system state register in a secure storage space. Otherwise the boot will fail and the system switches into a failed state. In case of a failed state the system may offer a Pristine Boot which as a fallback. Pristine Boot defines a device state after initial

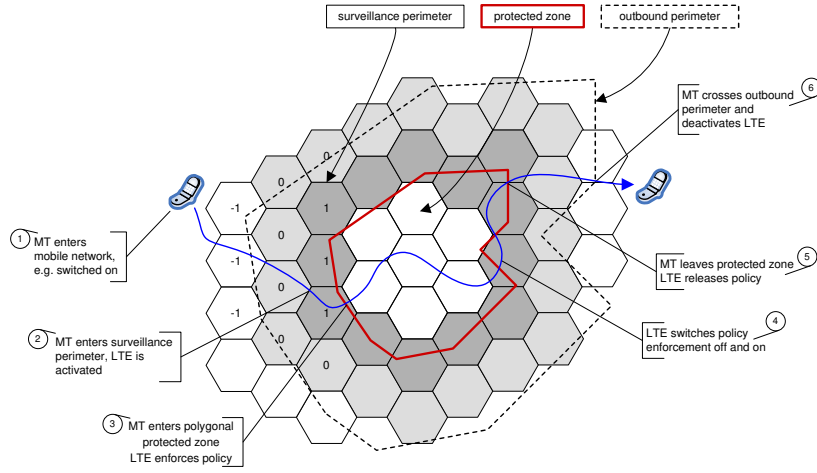


Fig. 3. Mobile station travelling through the zones and perimeters of a TLTA system.

factory installation where the life cycle of a device begins. Another use case for the Pristine Boot is an update process to rebuild the required credentials (e.g., RIM certificates) used during secure boot. If the secure boot of an MT succeeds the system on top can rely on the integrity of the system underneath. This includes all subsystems integrated in the platform including the LTE.

2) *Remote attestation*: A system which has performed a secure boot process on an appropriate platform constitutes a trustworthy base for other operations. This is not useful without means to convey this state in a reliable way to other entities. This process is called attestation in the context of TC. TC uses two concepts to implement this functionality: Platform Configuration Registers (PCR) and Attestation Identities (AI). A PCR reflects the system configuration reported by the measurement entity and is protected within the Mobile Trusted Module (MTM) against tampering. PCR values are created by combining digest values representing the measured component. Each value added to the PCR is also recorded in a log. Log and the corresponding PCR value together are testifying to the system state. To simplify the verification process, the MPWG has introduced a device side verifier. This verifier works as an agent close with the measurement system and holds RIM certificates. An Attestation Identity is embodied in a credential, and usually certified by a trusted third party, e.g., a Privacy CA, to attest that the owning MT contains a live, unaltered MTM. Producing the AI credential together with PCR values and measurement logs and signed by the AI private key to an external verifier, constitutes the attestation process proper. The verifier, in the particular case at hand, then has assurance that the MT operates an unaltered LTE on top of a set of trustworthy resources.

C. Mobility process

The *protected zone*, denoted pz , is for simplicity taken as the area circumscribed by a closed polygon in the plane which in turn is covered by cells of the mobile network. Now, assign the number 1 to all cells on the boundary of the closed, connected

set of cells covering the pz and call this set of cells c_1 . The *surveillance perimeter* (sp) is defined as outer boundary of c_1 . Call c_0 the set of cells adjacent to sp , c_{-1} the set of cells adjacent to the outer boundary of c_0 , and so on. Finally let the *outbound perimeter* op be a closed polygon such that $c_1 \subset \overline{op}$ and $\text{dist}(op, c_1) > 0$. This geometry is shown in Figure 3, wherein, op results from simply scaling pz .

Before TLTA can operate according to a TLTSR request, steps of device preparation and node configuration must be executed. For the latter, TLTA transmits a request to the AGW which configures the eNBs of c_0 and c_1 to execute the trust-enhanced handover described in Section III-A below, when an MT crosses the surveillance perimeter inbound. Device preparation is not required for trusted MTs already equipped with an LTE, thus it reduces to LTE enrolment. This can be done by secure software download, which is a major use case for TC-enabled devices, at any stage in the mobility process, e.g., when a device enters a c_0 cell.

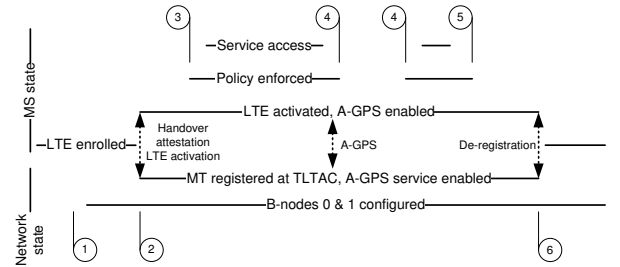


Fig. 4. Network and device states during the travel.

Figure 3 shows the travel of a mobile device MT through the zones. We describe this journey on a functional level, deferring details of communication protocols and procedures to Section III. The states of MT and the mobile network relevant to TLTA are shown in Figure 4. At the point marked (1), MT enters the mobile network in a normal operational mode, with deactivated LTE and A-GPS functions. Upon crossing sp at (2), the handover between a cell of c_0 and the

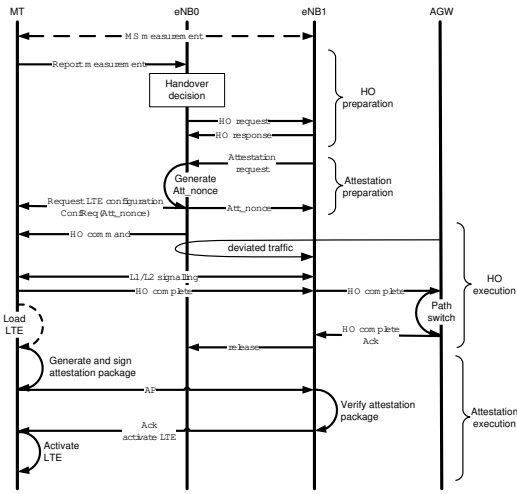


Fig. 5. Handover and attestation at the surveillance perimeter.

corresponding cell of c_1 is augmented by the activation of the LTE and the A-GPS, a remote attestation process, registration of MT with the TLTAC, and download of the authorisation policy, and the geometry of p_z to MT. From there on the device autonomously operates the location trigger to detect p using A-GPS and with the aid of an A-GPS support server (possibly a function of TLTAC). When MT enters p_z at (3), LTE enforces the policy, for instance unlocks a preassigned credential for service access. During sojourn in p_z , MT follows the policy and can for instance use a LBS whenever the user desires. At some points (4), MT may leave and re-enter p_z and LTE switches the enforcement of the policy off and on. LTE finally releases policy enforcement at point 5, but is deactivated only at crossing of op . At (6), LTE also actively de-registers MT with TLTAC. The triggering of location is cell-based only between points (1) and (2) and after (6), otherwise it relies on (assisted) GPS and MT' autonomous decision via LTE.

III. PROTOCOLS AND PROCEDURES

Here we present the technical concepts at the heart of TLTA, namely integration with the handover at sp , operation in p_z , and release at op .

A. Trust-enhanced handover at the perimeter

The trusted activation of the LTE, i.e., the activation of the LTE on the MT and a trustworthy report of that fact toward the network, when the device crosses the sp , is at the heart of the TLTA concept. The main idea is to integrate this process into the normal handover of MT between a cell of c_0 and of c_1 . Various handover protocols have been specified, and here we rely on 3GPPLTE, which offers advanced flexibility. 3GPPLTE handover (HO) is divided in two basic stages, HO preparation and HO execution. In the present case it involves an eNB of c_0 (eNB0) and of c_1 (eNB1), as shown in Figure 5. This process is augmented by two stages of remote attestation of the MT, regarding the presence and activity of the LTE, in our scheme. This design maximally separates the tasks between

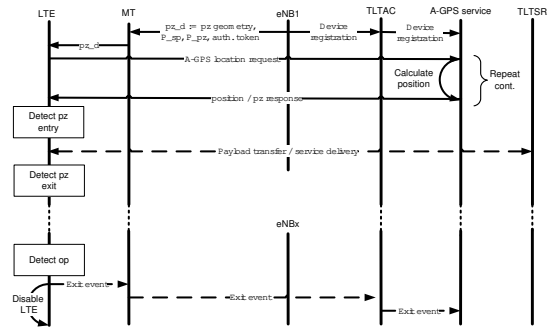


Fig. 6. Process after the activation of LTE and its interaction with TLTAC

the eNBs of c_0 and c_1 . The first one, attestation preparation, sets up eNB1 and MT to perform LTE activation and remote attestation. The second one, attestation execution, is performed after HO and does not interfere with this time-critical process.

When eNB1 is notified of an HO request of some MT, it issues an HO response to eNB0, and additionally notifies eNB0 of the necessity of a remote attestation of MT. The sole task of eNB0 is then to generate and distribute a particular nonce, as specified by the TCG's remote attestation protocol [7], for this purpose to MT and eNB1. This is a modification of the original TCG attestation protocol which combines eNB0 and eNB1 into one verifying party. eNB0 issues the [TCG conforming] attestation request to MT, along with the Att_nonce . The activation of LTE and attestation thereof is concluded only after HO. This means that the device loads the LTE (if it is not already present in its memory), generates an attestation package [7], and sends it to eNB1 only after the initial signalling with this B-Node is complete and acknowledged by the MT.

By attestation, eNB1 can be convinced that MT is in a trustworthy state and has an untampered LTE present. It then sends an acknowledgement to MT, including the signal to activate the LTE for operation within the sp .

B. Protected zone operation and release

Registration of the device at the TLTAC and download of the policy to the LTE on the MT are shown in Figure 6 and can be initiated by the AGW, eNB1 or the device itself. We have chosen the second variant in the figure. After registration with TLTAC, and optionally the A-GPS service, the MT/TLTAC pair can operate as a combination of policy enforcement point/policy decision point of an authorisation system in any desired separation of duties.

Policy enforcement can be divided into two levels for the area between sp and p_z and the interior of p_z with two separate policies called P_{sp} and P_{p_z} , respectively. Authorisation decisions can be felled either by LTE alone or by LTE in collaboration with LTACC in both cases. For the latter, LTE would transmit with an authorisation request a binary attribute to LTACC, stating whether the device is in p_z or not.

The location trigger is operated autonomously by the LTE, which periodically performs GPS measurements and requests

geopositioning from the A-GPS service. When the MT detects entry to p_z , the enforced policy is switched from P_{sp} to P_{pz} . MT can then, for instance, consume services from TLTSR. Upon MT crossing op , it notifies TLTAC, which de-registers it and signals the exit event to the A-GPS service (optionally, also TLTSR could be signalled).

IV. DISCUSSION

In this section we discuss the security of TLTA, questions of performance and practical issues, and finally sketch some concrete application scenarios.

A. Security

The two-tiered architecture of TLTA naturally divides security in two levels. Security on the sp rests on the integrity of the involved B-nodes eNB0 and eNB1, which is a precondition. Security in p_z on the other hand depends on the separation of tasks between TLTAC and the LTE. The security of the LTE is enabled by the unique features of trust-enhanced MTs, namely secure boot and attestation, features which are fundamental for TLTA. When a registered device enters or leaves p_z from or to sp , policy enforcement by LTE switches between the two policies P_{sp} and P_{pz} above. We discuss the security properties of the enforcement of P_{pz} .

The design entails that a security assessment of TLTA must distinguish between policies for *functional enforcement* and *access control*, respectively. The former means that certain functions on *all devices in p_z* shall be enabled or disabled. The latter allows certain content or services to be delivered or made available to the MTs registered with TLTAC. The essential difference between the two is that, in order to extend functional enforcement to all MTs in p_z , LTE activation must be ensured on all of them or the policy must be enforced otherwise, e.g., by out-of-band measures and processes. Access control is less security-critical. In contrast to functional enforcement, an access control policy is effectively enforced by the TLTAC, which will yield access only to MTs with active LTE accepting P_{pz} . In this case, LTE provides the added security that proliferation of access to content or services beyond p_z is effectively prevented.

Functional enforcement in TLTA is susceptible to certain attacks which do not apply to access control and whose general strategy is to subvert sp . The simplest and most effective is to cross sp and enter p_z with a disabled MT, or an MT shielded against network communication. Though one could attempt to detect such rogue MTs via the network when they are activated inside p_z , this might not be very efficient nor effective. A more sophisticated attacker could try to prevent the handover at the sp , e.g., using a beam antenna to tamper the MT's measurement of the base stations. In principle, this kind of attacks can only be mitigated by additional, physical access control procedures on p_z 's boundary.

A general caveat of architectures relying on a trusted platform built upon a hardware security anchor like an MTM is that it is more susceptible to side channel attacks than, e.g., a smart card. Applied to the TLTA concept this argument

could mean to imply that, e.g., location data is tampered with while in the MT's memory or in transit between processor and memory, respectively, the wireless modem. A hardening of the MT preventing this could be achieved using secure channels [8]–[10] (Texas Instruments' proprietary M-Shield technology is another example which could sensibly be combined with Trusted Computing for TLTA and other purposes).

B. Efficiency

The activities during the central stage of TLTA, the entrance to the surveillance perimeter, offer a great variety of implementation options. In particular it should be noted that though we used (A)-GPS as a prime example, any other autonomous or MT/eNB co-operative method for detecting entry to p_z such as triangulation, is applicable.

Let us briefly discuss the design choices taken in Sections II and III. The de-centralised architecture and operation of TLTA is designed with the central aim of reducing network load. This is only possibly with the desired level of security and enforcement if trust-enhanced MTs are used as central functional building blocks. TLTA is loosely coupled to the top-level of the cellular infrastructure. The TLTAC operates on the level of the network's Home/Visitor Location Register (HLR/VLR) and Mobile Switching Centre (MSC) And could be co-located or integrated with either one.

Signalling cost is a major concern for location management in cellular overlay networks [11], [12], which poses similar demands as location based authorisation. In our case, the two-tiered method of TLTA yields the largest advantage in this respect by leveraging the capacities of the edge of the network. In particular communication with MTs at the sp is completely borne by the eNBs and thus maximally de-centralised, and moreover MTs operate largely autonomous inside p_z . Furthermore, the protocol is designed such that the eNB of c_0 is passive, its sole essential task being the generation of the `Att_nonce`. This saves communication effort at the stage of node configuration, since only the eNBs of c_1 need to be activated to handle entry events. Another feature is the separation of inbound (sp) and outbound perimeter. It avoids judder, i.e., frequent switching on and off of the LTE and according (de)registration with the TLTAC.

A bottleneck could ensue if the physical access to the p_z is restricted, in the extreme case to a single cell and a large number of MTs enters sp . This can happen in particular in application scenarios for functional enforcement (see below). This concentrates the load for the TLTA entry protocol to a single eNB0, eNB1 pair. The problem can be alleviated by a) organisational measures to distribute entry points over the perimeter of p_z , or b) shifting the sp further away from p_z , i.e., to the boundary between cell layers c_{-n} c_{-n+1} , $n \geq 1$. A third option is to introduce extra cells *ad hoc*, e.g., mobile nano/pico-cells [13]–[15]. This is also an interesting option if the network's deployed B-nodes in the area are not capable to execute the TLTA protocol.

Regarding the mobile users respectively device owners, the forceful activation of the LTE is a potential infringement of the

proprietor's power of disposal. A similar consideration holds for Trusted Computing technology proper, on any platform. It has led the TCG to mandate activation and take ownership procedures for the hardware security anchor TPM/MTM. These concepts can sensibly be lifted to the level of applications intimately connected with and depending on TC. Furthermore, procedures for user notification and acknowledgement should be combined with TLTA.

C. Application Scenarios

The TLTA technology is of basic character, hence it is easy to envisage application scenarios in many sectors ranging from general m-commerce to public safety. We note but a few.

1) *High-tech trade fair*: Functional restriction policies can be enforced with exemptions. Consider a high-tech trade fair. p_z is determined by the fair's host so as to coincide with the physical entry barriers of the fair area. sp is a larger area so that visitors with TLTA-enabled MTs will already be registered with TLTA when passing the entry control. P_{pz} stipulates that cameras and sound recording facilities of devices are to be switched off by LTE. They then can freely pass through, while unprotected (or non-networked devices, e.g., cameras) are detected at the entry barrier and are confiscated. Countering industrial espionage is another use case. A company may use TLTA to disable MT cameras within the borders of their campus, while keeping the MTs of visiting executives operative for communication purposes.

2) *Sports stadium and concert hall*: The voice commentary on a sports event is broadcast encrypted to mobile devices in a stadium, which is the p_z . Only TLTA-enabled devices receive the decryption keys with the P_{pz} data managed securely by LTE. The TLTSR and service provider can simply broadcast the content and has no need to operate own access control facilities. In a concert hall, the live audio broadcast should add to the experience of the audience, and can be personalised in terms of language and otherwise. This shall not be able to be received outside of the concert hall, to avoid bootlegging.

3) *Mission critical communication*: MTs in a disaster area can be configured to receive emergency and alarming messages. This can be used to inform the public or emergency action forces but also to locate them within the danger zone. Standard mobile devices can co-operate with the special ones of action forces and inter-work over network boundaries, e.g., with TETRA networks [16], [17].

4) *Mobile gaming*: A game spread out over the area of a city requires to adjust the device side policies based on narrow location, e.g., when the user has reached a certain waypoint.

These scenarios have in common that they could in principle also be realised by authorisation not based on location, e.g., organisational processes, yet with varying methods to reach the desired enforcement level. The benefit of TLTA is a unified authorisation method scaling with security requirements.

V. CONCLUSION

We have presented a novel system for the enforcement of authorisation policies according to location attributes. The

salient features of i) largely de-central operation, and ii) strong enforcement level rest on a few key ideas. First, trust-enhanced devices combine functions of secure location triggering with policy enforcement. Second, establishment of the protected zone policy enforcement is efficiently integrated in the handover between cells. Third, location trigger operation is two-tiered combining cell-based location with precision location methods like (A)-GPS. These concepts optimally leverage network and device resources and concurrently provide a high security level. Potential applications abound, some of which are only possible with TLTA or related concepts employing trusted devices. Implementation of TLTA seems feasible and economically viable, once TC-enabled devices become widely available.

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