Viability of ISI-Based TETRA over Satellite

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Abstract: Satellite communications, by its very nature of providing wide-area coverage, can play an important role in interconnecting TETRA networks. A satellite link may be used to support any of the interfaces in TETRA network. However, the selection of particular interface applies to specific scenarios and provides different advantages and disadvantages. The viability of a satellite link for the interconnection of two TETRA networks using the Inter-System Interface (ISI) is studied with respect to desired functionality and QoS. ISI-based TETRA over satellite can be used in emergency situations when no terrestrial infrastructure exists between the two networks, as well as in normal operations as an alternative to ground based interconnection infrastructure. The response time of different services in a given network architecture is of primary concern because large propagation delay is the main source of service degradation. A modified version of critical path analysis, as it applies to protocols, is used to estimate total propagation delays for a set of ISI services. The appealing property of the critical path length is that it gives an accurate estimate of total propagation delay for a given service and thus represents a quantitative measure of QoS degradation as experienced by the end user. The results presented show larger degradations of QoS for the group call scenarios. The most disturbed are acknowledged group call setup and group call maintenance. A Performance Enhancing Proxy (PEP) is proposed to improve the performance of the TETRA services over the ISI if satellite links are involved.

Key-Words: TETRA, satellites, Inter-System Interface, propagation delay, critical path, QoS

1 Introduction

The need for intercommunication between different independent Professional Mobile Radio (PMR) networks has been a requirement for many years. This especially holds for public safety and related organizations in addressing major incidents. The pan-European TETRA standard is a major step towards interoperable communication equipment in the field of emergency services [1]. TETRA networks make possible closer co-operation between police, fire brigade, ambulances, army, border security forces and others. TETRA provides very fast call setup time (300ms), which is crucial for the public safety and emergency systems. Network supports both semi-duplex operations for efficient group communications and duplex type of individual calls. Implemented are voice, circuit switched and packed switched data services as well as supplemental services like remote control, supervision [2], and paging [3].

Currently, a number of concepts and scenarios are looked into that involve integration of satellite systems and TETRA networks; from linking a small capacity TETRA base station via satellite links to interconnecting two standalone TETRA networks. Here, the latter option is investigated further. In particular, the applicability of the Inter-System Interface (ISI) is studied. ISI is a set of standards that defines an interface for a TETRA service across network boundaries. The ISI specification is concerned with the inter-working of different TETRA networks while inter-working with other public networks is the subject of other interfaces and gateways (PSTN, ISDN, PDN, IP).

The paper is structured as follows. In Section 2 the ISI-based TETRA over satellite scenario is presented with an overview of other related studies. The response time of different services in a given network architecture is of primary concern because large propagation delay is the main source of service degradation. Critical path analysis of the network layer protocols over the ISI is used as the main tool. Section 3 defines a critical path as well as a critical path length. Services supported over the ISI are studied next from the standpoint of message flows across the interface in order to establish potential QoS degradations. Further, an influence on the TETRA timers is discussed with some suggestions on recommended timer values. The findings are derived solely on the examination of the inter-SwMI protocols as described in ETSI standards EN 300 392-3 (sub-parts 1–5) [4]. Section 4 presents some guidelines to improve performance of previously analyzed services by exploring the concept of a Performance Enhancing Proxy, while Section 5 concludes the paper.

2 ISI over Satellite

ISI-based TETRA over satellite is a specific interconnection scenario for two TETRA networks, which can be used in emergency situations when no terrestrial infrastructure exists between the two networks, as well as in normal operations as an alternative to ground based interconnection infrastructure. Using satellite links as part of the integrated emergency communication system efforts is not new. Studies exist that investigate integration of satellites and TETRA system. They differ in assumptions on how much and what parts of the communication infrastructure would be broken down or destroyed in an emergency situation. Satellites have been already successfully introduced within a TETRA system in 2003. The trial was performed by Motorola, NATO and C3 Agency. WISECOM project introduces a WAT (WISECOM Access Terminal), which cuts the core of a TETRA network in two parts, disaster and disaster-safe segment [5, 6, 7]. The satellite link acts as a backup link connecting a TETRA base station to fully functional TETRA switching and management centre. On the other hand, to the best of our knowledge, no satellite-related study has been done on interconnecting two TETRA networks using standard ISI.

2.1 Network Architecture

Viability of using a satellite link for the interconnection of two TETRA networks is studied in the overall network architecture illustrated in Fig.1. Each TETRA network consists of Switching and Management Infrastructure (SwMI) with accompanying base transceiver stations, line and mobile stations [8, 9]. The representation chosen is intended to show only important system entities that participate in ISI-related services. In addition to the interface entity (ISI), Call Control (CC) and database entities are shown. The connection between two SwMIs is a single satellite connection from a single interface point in one SwMI to a single interface point in the other SwMI.

Mobile Stations (MSs) and Line Stations (LSs) are also depicted in Fig.1. While LSs typically represent a control room console terminal or dispatcher unit connected to a TETRA SwMI over an ISDN network, the MSs are mobile and may move from the home SwMI to the visited SwMI and vice versa. MSs are hand-portable or vehicle-mounted mobile units.

The inter-system services can be roughly classified into services providing individual and group call setup, call restoration, loop avoidance, transmission control and mobility management, the latter covering migration, authentication, group attachment/detachment and other services.

2.2 Inter-System Interface

ISI is a set of standards that defines an interface for a TETRA service across network boundaries. It can connect several TETRA networks together. TETRA standard services over ISI are embedded into QSIG and are described in [4]. In practice, the services that can be supported are those defined under air interface interoperability.

The Inter-System Interface (ISI) is built on top of the Private Signalling System 1 (PSS1) protocol stack. The PSS1 is an ISDN based signalling protocol for interconnecting Private Branch Exchanges (PBXs) in a Private Integrated Services Network (PISN). The PISN standards are produced by the European Manufacturers Association (ECMA) and submitted to ISO for adoption as global standards. PSS1 is known also as QSIG and was originally developed by ETSI. Because it is not owned by any one company, it allows interoperability between communications platforms provided by different vendors.

At the top of the protocol stack an application-level protocol ROSE (Remote Operation Service Element) is used to convey ANF-ISI Protocol Data Units (PDU). The protocol is specified in ITU-T Rec. X.229. Follow the Generic Functional Protocol (ISO/IEC 11582), the PSS1 basic call protocol (ISO/IEC 11572) and ETS 300 402-1,2 (Q.920, Q.921) [10, 11].

The user data in a group call or in an individual call is sent using B channels. The standard data rate is 64 kbit/s. As an option the user data sent in one air interface slot can be encoded at the ISI into an 8 kbit/s bit stream. This encoding has not yet been defined for either data calls (at 7.2 kbit/s, 4.8 kbit/s or 2.4 kbit/s) or speech calls. N slots at the air interface, with $N = 2$ to 4, would be multiplexed into $N * 8$ kbit/s streams, which can still be carried by the same 64 kbit/s B channel. The corresponding straightforward multiplexing is defined in ITU-T Recommendation I.460 [12]. 8 kbit/s channels are still only an option. When this option is standardized, N slot calls over the ISI will be treated as PSS1 multi-rate calls.

2.3 QoS Requirements

The TETRA standard requires call setup time to be below 300ms. This requirement is valid within a single SwMI. It is unreal to expect this bound to be preserved over the ISI even if no satellite links are em-

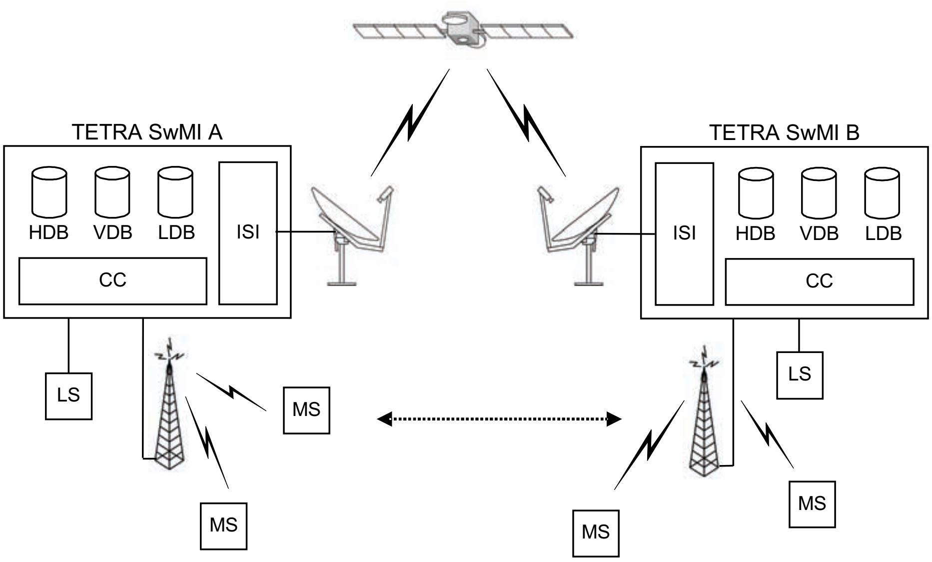

Fig. 1: Network architecture of the ISI-based TETRA over satellite scenario

ployed. Because there are no requirement for the ISI communications in the standards except not to violate the existing timers, one could adopt QoS criteria defined in the Three-Country Pilot (3C) project [13]. The aim of the project was to capture the ISI requirements that are required to connect public safety systems of the Netherlands, Belgium and Germany together. Note that a mesh of permanently leased lines was assumed to interconnect the three TETRA systems. The following are inter-SwMI communication requirements as derived in that project:

- Non disturbing call setup delay should remain under 1s for inter-SwMI calls. Note that call setup delay is defined as the delay experienced by the user between pressing push-to-talk button and typically getting an audio indication for permission to talk.
- The end-to-end audio delay experienced by the user should be bounded by 0.7s.
- The migration registration procedure in the visited network should not be longer than the registration in the home network for more than 1s.

Typically, it will be necessary to provide both authenticity and confidentiality on the ISI. This ensures that the other SwMI cannot be impersonated and that the exchanged traffic cannot be intercepted. The work on ISI security has not been completed, therefore an alternative solution to this problem in the form of commercial of-the-shelf (COTS) should be provided [14]. Note that the network architecture in Fig.1 does not show specialised encryption devices that would be needed on both sides of the link and would additionally contribute to the delay.

3 Critical Path Analysis

We use a modified version of critical path analysis, which is otherwise a method for pinpointing the sources of delays in protocols [15, 16], to estimate the total propagation delay for a given service. The main observation of the critical path analysis, as it applies to protocols, is that only some of the messages exchanged are responsible for the overall protocol time. Many messages may be transferred in parallel, so that they overlap each other. Such messages do not affect overall response time. A critical path in protocol execution is defined as the lengthiest sequence of messages, for which Lamport's happened-before relation exists [17].

If we observe only messages that are exchanged through the ISI interface and establish temporal relations among them then the actual length of a critical path found gives a direct measure of the total delay introduced due to propagation delays. The implications on QoS degradations can be drawn next.

In order to estimate the response time of the ISI services, a geostationary satellite is assumed. As a result of its high altitude, radio signals take approximately 250ms to reach and return from the satellite. One should also take into account necessary overhead delay that has a source in the error correction techniques, queuing and elsewhere. For the purpose of this study, 300ms propagation delay is used to quantify service disturbances.

3.1 Individual Call

Individual call is a teleservice in which a point-to-point call is established between two parties. The

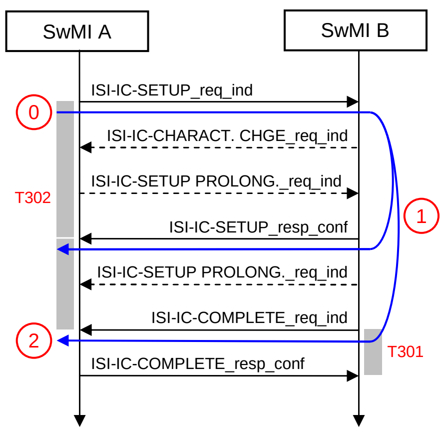

Fig. 2: ISI message exchange for individual call setup with on/off hook signalling

calling party receives acknowledgement of the call progress, i.e. answered, unanswered, rejected, etc.

The ISI support for individual call enables calls to be setup by a user registered in one TETRA network to another user registered in another TETRA network. In addition to this baseline support, call restoration scenario is also covered. A need for call restoration emerges when a user has migrated to another TETRA network while having an established call. Other TETRA signalling information can also be passed between two SwMIs supporting TETRA individual call.

As an example scenario, a time line diagram for call setup with on/off hook signalling is shown in Fig.2. The calling user is located in SwMI A, while the called user is located in SwMI B. The home of the called user is either SwMI A or SwMI B. The exchanged messages shown are derived from the Message Sequence Chart (MSC) in [4] and from the call setup scenario in [18]. Only ISI level messages and important timers are shown. The critical path is represented by a curved line, reflecting the fact that the message could not have been emitted before the corresponding message was received.

ISI-IC-SETUP is a confirmed message sequence that starts a call setup procedure on inter ISI communication channel between SwMI A and SwMI B. The confirmation is sent by SwMI B upon the first response of the called user.

If the call is established using on/off hook signalling, ISI-IC-COMPLETE confirmed message sequence needs to be exchanged, originating in SwMI B. Mandatory fields of the request carry values such as terminating SwMI Mobile Network Identity (MNI), call time-out, connected party identity, simplex/duplex selection, etc.

The critical path length of the mandatory exchange equals 2. Note that ISI-IC-SETUP_resp_conf and ISI-IC-COMPLETE_req_ind may be considered parallel for the purpose of critical path analysis and that the length of critical path is measured from the standpoint of the call originating SwMI. The optional messages ISI-IC-CHARACT CHGE and ISI-IC-SETUP PROLONG have no influence on the critical path length because the messages are unacknowledged and can be parallel to the mandatory information flow.

Satellite interconnection has a minor influence on the individual call setup time. 2 propagation delays introduced are within the limits of the call setup timeout values. The call setup timer T301 for called SwMI is affected by 2 propagation delays. The introduction of a satellite has the same impact on the call setup timer for calling SwMI, i.e. T302. The maximum values for T301 and T302 are 30s and 60s, respectively. The predefined value is 30s and the allowed values are 1s, 2s, 5s, 10s, 20s, 30s and 60s [18].

Similar analysis can be performed for the rest of individual call scenarios. Due to space limitations we only summarize the final findings in Table 1. For each scenario investigated, a critical path length and the timers involved are given. The final column shows QoS implications based on the QoS requirements. The individual call scenarios are mostly below 1s requirement if only propagation delays are accounted for. An exception is the transmission control scenario for a half-duplex mode with 1.2s delay caused by the propagation.

3.2 Group Call

Group call is point-to-multipoint service. The baseline service connects calling user to more than one called user without waiting for confirmation as to whether or not the called users are ready to communicate.

Several inter-SwMI scenarios need to be considered in order to analyze the impact of satellite link on the group call QoS. First, different SwMI roles in the ISI group call scenarios have to be clarified:

- OSwMI - Originating SwMI: The originating SwMI is SwMI in which call originates, either being an individual or a group call.
- GSwMI - Group Home SwMI: Home of the GTSI, i.e. the SwMI where the network code (MNC) is equal to that of the group (GTSI).
- CSwMI - Controlling SwMI: Maintains call extensions over two or more SwMIs. Usually, CSwMI is the group home SwMI.
- PSwMI - Participating SwMI: A non-home SwMI which has some members of the group.
- LCSwMI - Linking controlling SwMI: SwMI that

Table 1: Individual call scenarios—critical path lengths, timing issues and QoS implications

Scenario	Critical Path Length	Timers Influenced	QoS Implications
call setup with on/off hook signalling and call setup using direct setup signalling	2	T301 – call setup timer for called SwMI (2 propagation delays), T302 – call setup timer for calling SwMI (2 propagation delays), 1s and 2s should be avoided as timer values	300ms $<$ 2 propagation delays (0.6s) $<$ 1s
call restoration	2 (actual disruption of the ongoing call lasts 3 propagation delays)	T306 – call restoration timer for point-to-point calls (2 propagation delays)	disruption of the ongoing call for at least 3 propagation delays (0.9s), still below 1s
loop avoidance	2	T302 – call setup timer for calling SwMI (2 propagation delays), 1s and 2s should be avoided as timer values	influenced only call setup time, call proceeds without satellite involvement, 300ms $<$ 2 propagation delays (0.6s) $<$ 1s
transmission control (half-duplex mode)	3 (1 additional delay for ex-calling user to start receiving)	T311 – call transmission timer (2 propagation delays)	break between two consecutive transmissions takes at least 4 propagation delays (1.2s), which is more than 1s

controls the linking of one of its own groups to one or more groups from other SwMIs.

A number of scenarios may occur when a group call is setup over the ISI. First, baseline unacknowledged group call setup is considered. Some important events after the call has been setup are analyzed latter on. The scenarios can be systematically enumerated by considering all possibilities for the involved parties. In order to do that, we should distinguish not only the calling from the called user, but also participating SwMI roles. Further, a calling user may be located in its home network or in the visited network, trying to setup a group call to a home group or to a foreign group, i.e. a group with home different from home of the user. Taking into account limitations, removing symmetrical and invalid scenarios, the number of different cases reduces significantly. In the following the most common ISI message flows are analyzed. In addition, the worst case scenario involving linked groups and unfavourable placement of other roles and parties is also shown.

The baseline unacknowledged group call setup scenario consists of a visiting user in SwMI B calling its home group ID. There are group members in both SwMIs. Therefore, under the terminology used for describing group calls between multiple SwMIs, the originating SwMI is SwMI B, which is also a participating SwMI, while SwMI A is the group home SwMI and as such also a controlling SwMI. The message flow diagram in Fig.3 and conclusions derived also holds for the scenario in which the user in SwMI B is calling a foreign group over the ISI.

First, a call request is forwarded to the group home SwMI using ISI_ORIGINATING SETUP message. This message is sent when a group call setup has been initiated in a SwMI other than the group home SwMI or linking group home SwMI. In response, a general information message ISI_INFO from the controlling SwMI A to the originating SwMI B is sent. ISI_SETUP is sent by the controlling SwMI to all SwMIs where members of the group call exists. The message must be confirmed. In the final stage, ISI_CONNECT is sent by the controlling SwMI to the originating and participating SwMIs to inform them to through connect. At this point in the call, the originating SwMI connects the calling user.

In total 4 propagation delays are experienced by

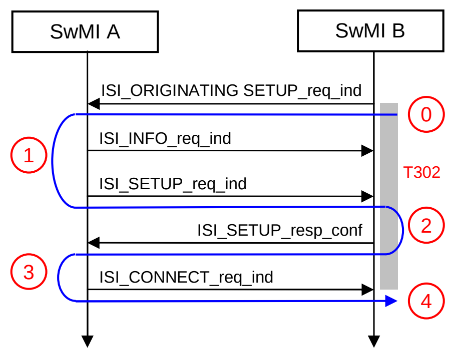

Fig. 3: ISI message exchange for baseline unacknowledged group call setup

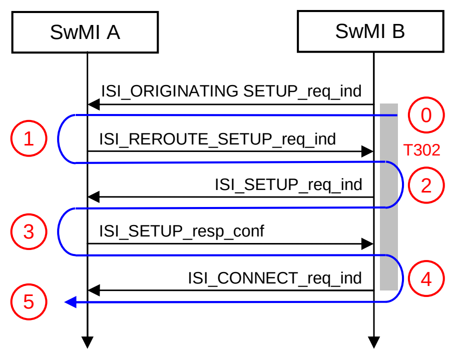

Fig. 4: ISI message exchange for the worst case linked group call setup scenario

the calling user to setup a call from a visited SwMI B. Additional propagation delay is needed for the group users in SwMI A to start receiving data. The critical path length may interfere with timer T302 (call setup timer for calling user) if set too low. Among the allowed values, 1s and 2s should be avoided. If the originating SwMI is SwMI A instead of SwMI B, the critical path length reduces to 3 with no additional propagation delay for users in SwMI B.

In Fig.4 the most unfavourable placement of roles and parties is chosen. Two linked groups exist, one in SwMI A and other in SwMI B. SwMI B is linking controlling SwMI, which controls the linking as the group home of the linked group. A calling user is visiting SwMI B, which means that he is calling a group ID in his own network.

SwMI A is not linking controlling SwMI and the ISI_ORIGINATING SETUP is re-routed back to the linking controlling SwMI B. This step cannot be avoided, because when groups are linked, the linking controlling SwMI has no knowledge of the individuals belonging to each linked group. In total, 5 messages in sequence are needed to setup a call, which is the worst timing within the unacknowledged group

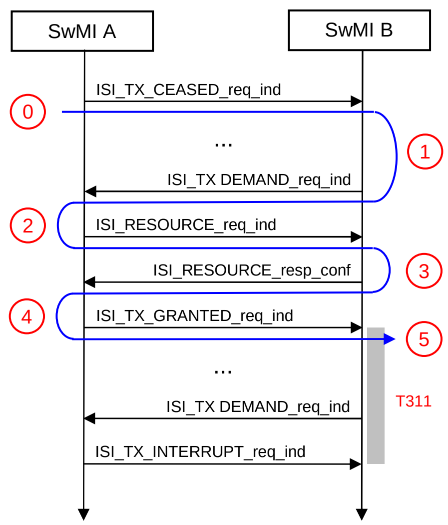

Fig. 5: Group call maintenance messages on the ISI between two SwMIs

call setup scenarios. Up to 4 propagation delays are affecting timer T302.

Polling in acknowledged group setup is always performed after the call has been already setup. This would have no consequence on TETRA-over-satellite analysis if the controlling SwMI decides to let the call proceed immediately. However, the controlling SwMI can decide to give user permission to transmit after the participating SwMIs have responded to the polling request. This last case adds 2 additional propagation delays to those identified above.

Switching between the transmitting parties in Fig.5 is somehow similar to half-duplex operation in the individual call scenario, at least with respect to the ISI messages exchanged. When currently active user stops transmitting, an ISI_TX_CEASED message is sent to the group members. If next group member wants to transmit in SwMI B, four messages have to be exchanged with the controlling SwMI A, i.e. ISI_TX_DEMAND, ISI_RESOURCE req/conf and ISI_TX_GRANTED. The group members are notified about the new transmitting user via ISI_TX_GRANTED. After currently transmitting user finishes and before he starts receiving actual data from the next transmitting party in different SwMI, a pause occurs in the length of at least 6 propagation delays.

Group call restoration takes place while active group member migrates from one SwMI to the other SwMI. The migrating user continues to receive group transmission. Several call restoration mechanisms are differentiated in TETRA standards. The most simple is to extend the group call to a new SwMI, where the call does not exist, upon transmission granting. Under this scenario, current transmission is interrupted, while the next transmission reaches all the group members. The scenario dealt with in the following assumes that the migrating user makes an explicit request to restore the call while he is still attached to the old SwMI. The SwMI where he is migrating has no group members for given group. The propagation overhead is 2 with an additional delay for the transmitted data to reach new SwMI destination. This would cause notable break in the transmission stream, but the transmission will continue after the pause. Call restoration timer for point-to-multipoint calls is used in SwMI A. It can be set to minimum 2s and maximum 8s. Minimum values should be avoided to take into account other delays present in the system.

Table 2 recapitulates the findings for the group call scenarios. The results presented show larger timing degradations. The most disturbed are acknowledged group call setup and group call maintenance, the latter even for 6 propagation delays. The end-to-end audio could be well beyond the limit of 0.7s.

3.3 Mobility Management

ISI mobility management services complement intra-mobility management. Mobility management is a set of various signalling procedures for user identity registration and location updates. Although mobility management is a key service of TETRA that distinguishes a mobile network from a fixed network, from the viewpoint of a critical path analysis those services are less crucial because they are executed in background without an involvement from the user. The quality of service to the user is affected in a migration scenario in combination with a call restoration and in a group attachment scenario. Note that the mobility management services extended over the ISI include migration, de-registration, profile update, authentication, Over The Air Re-keying (OTAR), group attachment and detachment, database recovery and group linking.

A user is said to migrate when it moves to a new location area in a network with a different Mobile Network Code (MNC). Usually, user does not have a subscription for the new network. This is known as roaming in GSM. The main purpose of the migration services is to update the individual subscriber home SwMI and the visited SwMI with the new location information. Several variants of the migration scenario exist. Mainly, they differ in the type of profiles exchanged between the involved SwMIs. In the simplest migration scenario the visited SwMI uses a predefined profile for the user rights. Lengthier scenarios require the exchange of the actual user profile with the home SwMI. Supplementary service (SS) profile is dealt with separately and requires an additional ex-

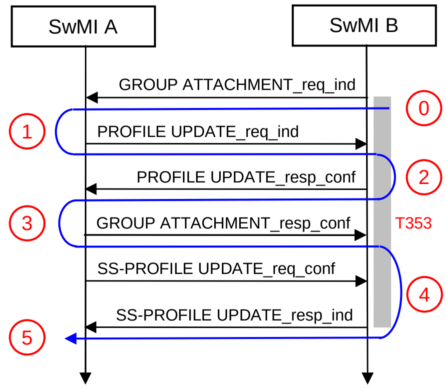

Fig. 6: ISI message exchange for the attachment of the first group member

change of ISI messages.

Although the critical path length of a migration scenario with the lengthiest sequence of messages consists of 4 sequentially exchanged messages, only the first MIGRATION has an impact on the call restoration procedure. Namely, migration may not be completed in full before a call restoration is started. If required, the call restoration is invoked after home SwMI approves migration, i.e. after the first message, even if the final approval has not been sent.

In order to enable group communications, a user should join a group. If this is done in the visited SwMI, which is not the group home SwMI, the visited SwMI invokes the group attachment service across the ISI. The attachment must be requested by the user, which makes this service important from the QoS perspective. The group home SwMI may also invoke the service across the ISI in order to attach a migrated user to the group. The migration service should have been invoked and completed for the user.

For the critical path analysis we should distinguish the first from the subsequent group attachments. The first attachment is needed if a group is not previously attached to any subscriber in the visited SwMI. The visited SwMI needs a migration profile of the group. The profile is either created from the predefined profile or exchanged across the ISI. As for individual migration profiles, basic and supplementary service group migration profiles are defined. In the worst case scenario when both group migration profiles are exchanged, the message flow in Fig.6 is expected.

The ordering of profile messages results in a critical path length of 5 propagation delays. Only 2 propagation delays are involved in the subsequent attachments or in the attachment without a group migration profile exchange. The case when the home SwMI attaches the user is slightly less demanding. It takes 4 propagation delays due to inherent parallelism in the

Table 2: Group call scenarios—critical path lengths, timing issues and QoS implications

Scenario	Critical Path Length	Timers Influenced	QoS Implications
baseline unacknowledged group call setup	4 (1 additional delay for users in other SwMI to start receiving data)	T302 – call setup timer for calling SwMI (4 propagation delays)	4 propagation delays (1.2s) > 1s
worst case unacknowledged group call setup	5	T302 – call setup timer for calling SwMI (4 propagation delays)	5 propagation delays (1.5s) > 1s
acknowledged group call setup	7	T302 – call setup timer for calling SwMI (6 propagation delays)	7 propagation delays (2.1s) > 1s
group call maintenance	5 (1 additional delay to route data between two SwMIs)	-	break between two consecutive transmissions takes at least 6 propagation delays (1.8s), which is more than 1s
group call restoration	2 (1 additional delay for migrating user to resume receiving)	T307 – call restoration timer for point-to-multipoint calls (2 propagation delays), 2s should be avoided	break in the ongoing transmission for at least 3 propagation delays (0.9s)
other scenarios	-	-	non-critical

ISI message ordering. Table 3 summarizes the above findings.

3.4 Short Data Service

The ISI support for short data service enables transport of SDS messages between SwMIs. A message is transparently taken as presented by the originating SwMI and transported to the peer SwMI. Each message is considered independent. Therefore, the delivery of messages is affected by a single propagation delay. Taking into account that this is a datagram service with no real-time constraints, there are no limitations to distribute the messages over the satellite.

4 Performance Improvements

The impact of satellite interconnection on ISI-based services is definitely notable. While some services are less important, e.g. call restoration or loop avoidance, other services require more attention. Unacknowledged and acknowledged group call setup as well as group call maintenance are among most important for any real emergency scenario. The assessed service prolongation delays are in range of seconds and can significantly deteriorate service perception by the end users. It is worthwhile to look for performance improvements, at least for these services. Since inter-SwMI protocols are already standardized and thus cannot be changed, the applicability of performance enhancing proxy functionality should be investigated for these particular services.

In general, Performance Enhancing Proxies (PEPs) are designed to improve the end-to-end performance of some communication protocols by breaking the end-to-end connection into multiple connections. For example, this allows TCP to overcome the low window size problem when connections involve satellite links (RFC 3135). The end-systems are not aware of proxies and can run unmodified. There are several types of PEPs. A PEP can either split the connection by pretending to be the opposite endpoint or interfere with the transmitted messages, also known as protocol spoofing. Further, PEPs can be either on both ends of the satellite link that cause the performance degradation or just at one end, which is far less common. For the purpose of ISI-based TETRA over satellite a symmetric PEP placed on the both ends of the satellite leg is seen as the most promising. Note that symmetric PEPs behave equally in both directions. The communication between peering PEPs could use an arbitrary protocol.

Table 3: Mobility management scenarios—critical path lengths, timing issues and QoS implications

Scenario	Critical Path Length	Timers Influenced	QoS Implications
migration services	4 (migration may not be completed in full before a call restoration)	T351 – registration response timer (4 propagation delays)	additional propagation delay for the call restoration scenarios, resulting in breaks that take at least 4 propagation delays (1.2s)
authentication	3	-	runs in parallel with migration
first group attachment	5	T353 – attach/detach response timer (5 propagation delays)	delay between joining a group and receiving the first data equals at least 5 propagation delays (1.5s)
subsequent group attachment	2	T353 – attach/detach response timer (2 propagation delays)	delay between joining a group and receiving the first data equals at least 2 propagation delays (0.6s)
group detachment	2	T353 – attach/detach response timer (2 propagation delays)	non-critical
other services	-	-	non-critical

Although it is not the purpose of this report to further elaborate on ISI PEP, a short discussion on possible PEP operation is given next. We restrict ourselves to a group call maintenance scenario. The critical path analysis showed that after currently transmitting user finishes and before he starts receiving actual data from the next transmitting party in different SwMI, a pause occurs in the length of at lest 6 propagation delays. The scenario is illustrated in Fig.5.

Suppose two PEPs are installed at each side of the satellite link, PEP A and PEP B. PEP B should act on the receipt of ISI_TX_DEMAND_req_ind from SwMI B. In addition to forwarding the message to PEP A located on the other side of the satellite link, an artificial ISI_RESOURCE_req_ind should be returned to SwMI B. Next, ISI_RESOURCE_resp_conf would be intercepted by PEP B. This time an artificial ISI_TX_GRANTED_req_ind is sent back to SwMI B, which effectively allows the requesting user in SwMI B to start transmitting. In the meantime, PEP A forwards ISI_TX_DEMAND_reg_ind to SwMI B. On the receipt of ISI_RESOURCE_req_ind starts its proxy functionality, which complements the actions of PEP B. PEP A answers SwMI A by an artificial ISI_RESOURCE_resp_conf, which triggers SwMI A's ISI_TX_GRANTED_req_ind. On that point, PEPs employ synchronization phase, in which compatibility of the real and artificial parameters used in the process are checked. If the parameters match, no further action is taken and the transmission may proceed. Otherwise, a rollback procedure must be performed, that would probably include a termination of the artificial transmission grant sent to SwMI B. The requested contents of the artificially generated messages consist of fields such as resource indicators, notification indicators, transmission request permission, transmission grant, encryption control and others, which can be either set to appropriate values or learned from the real messages. The exact solution is beyond the scope of this paper. In the above proposal 4 propagation delays are eliminated from the group call maintenance scenario, but more in-depth analysis of the solution viability is required.

Other types of performance improvements can be achieved when two TETRA networks are interconnected. The ISI interconnection would be normally implemented using fiber, cable or microwave transmissions where bandwidth is not normally concern. Once fiber is installed, there is not big difference in using one E1 versus eight E1s. Satellite transmission however, is very bandwidth sensitive since every kHz of satellite bandwidth must be leased and incurs an additional cost. When implementing TETRA links over satellite, it is important to minimize the required link bandwidth in order to reduce operating costs. Because the standard data rate at ISI is 64 kbit/s per call, bandwidth reduction techniques may be employed to improve cost performance of the ISI-based TETRA over satellite scenario. It is relatively easy to take a brute force approach and simply transmit the E1 interfaces over the satellite. The principal techniques for improving transmission efficiency are voice compression, the elimination of unused timeslots and statistically multiplexing of the signalling channels.

5 Conclusion

ISI-based TETRA over satellite can play an important role in major incidents when cross-border cooperation of rescue teams is required. Situations can emerge, in which fast interconnection of the home and foreign network is needed while available land infrastructure would be scarce.

Even though TETRA operation is standardized, there are still ongoing research topics [19]. In the present paper the network layer protocol over the ISI in a multitude of standardised services was studied. The main inputs to the study were ETSI standards, from which performance estimates and potential limitations of this particular interconnection topology were deduced. No actual trial has been performed. The present study can be considered as a viability test before actual on-field exercise. Other limitations, which cannot be accounted for based solely on the content of relevant standards, are possible.

Introduction of a satellite link between two TETRA systems is questionable mainly due to a significant increase in the propagation time. In particular, we find that the individual call scenarios are mostly below 1s requirement if only propagation delays are accounted for. An exception is the transmission control scenario for a half-duplex mode with 1.2s delay caused just by the propagation. The results presented show larger degradations of QoS for the group call scenarios. The most disturbed are acknowledged group call setup and group call maintenance. Among the migration services, the first group attachment performs the worst. Use of pre-defined profiles in migration services can improve the situation.

A PEP is proposed to improve the performance of the TETRA services over the ISI if satellite links are involved. The ISI PEP is currently just a rough idea, which will be developed further in the future.

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