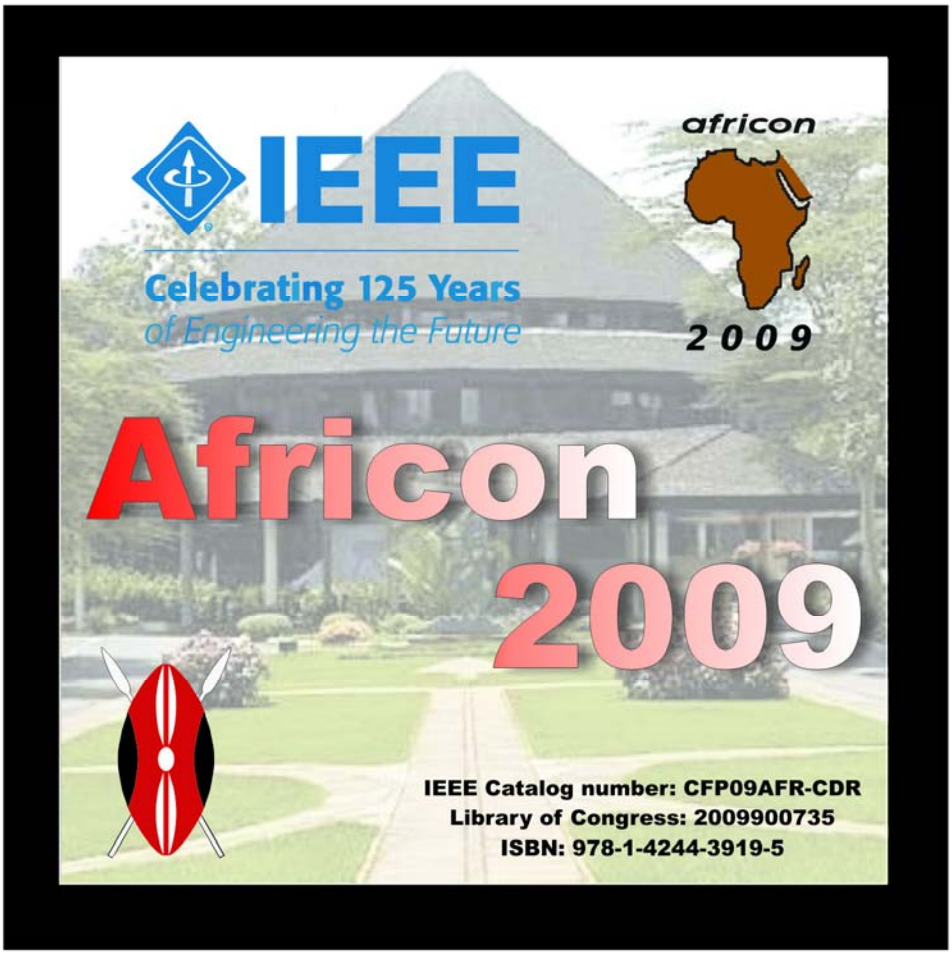

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Network layer based redundancy for time-critical VoIP applications

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Abstract
Voice over Internet Protocol (VoIP) applications are making their way into safety-critical environments. If voice data has to be transmitted in such environments, the connection must not fail and the network has to recover quickly. Additionally, the use of specialized systems that are tailored to a certain application is not a preferred solution. Instead, the use of commercial-off-the-shelf (COTS) hard- and software is required. This paper discusses the use of standardized hard- and software as well as network protocols to allow failover times within the range of milliseconds. A redundant end-system and its network coupling are presented. The Layer 3 protocol OSPF and the combination of OSPF with the protocol-independent Hello protocol BFD are investigated to fulfill the requirements. The tests and the achieved results show a significant reduction of the convergence time.

Index Terms
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Not Available

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Wed 23 Sep	08:30	08:45		Welcome KN: Mugo Kibati					
	08:45	09:30							
	09:30	09:45						Break	
	09:45	11:15	TT-CA-1	TT-CSP-1	TT-EES-1	TT-EIR1			
	11:15	11:30						Break	
	11:30	13:00	TT-CA-2	TT-CSP-2	TT-EA-1	TT-EIR-2			
	13:00	14:20					Lunch		
	14:20	15:50	TT-CA-3	TT-CSP-3	TT-EAH-1	TT-MS-1			
	15:50	16:05						Break	
	16:05	17:35	TT-CA-4	TT-CSP-4	TT-EAH-2	TT-MS-2			
Thu 24 Sep	08:30	09:15		KN: Dietmar Dietrich					
	09:15	09:30						Break	
	09:30	11:00	TT-EPS-1	TT-CSP-5	TT-CIS-1	TT-MS-3			
	11:00	11:15						Break	
	11:15	12:45	TT-EPS-2	TT-CSP6	TT-CIS-2	TT-EDC-1			
	12:45	14:05					Lunch		
	14:05	15:35	TT-EPS-3	TT-CSP-7	TT-LEO-1	TT-EDC-2			
	15:35	15:50						Break	
	15:50	17:20	TT-EPS-4	TT-PED-1	TT-EM-1				
	18:30	22:00						Gala Dinner	

Fri 25 Sep	08:30	09:15		KN: Daniel Foty				
	09:15	09:30						Break
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	11:00	11:15						Break
	11:15	12:45	TT-EPS-6	TT-PED-3	TT-CMA-2	TT-MCA-2		
	12:45	14:05					Lunch	
	14:05	15:35	TT-CS-1	TT-PED-4	TT-IM-1	TT-MCA-3		
	15:35	15:50						Break
	15:50	16:05		Closing				

Preliminary Program - Tracks

Program
Program papers

Code	Name
TT-CA	Control and Automation
TT-CIS	Computer, Information Systems and Software Engineering
TT-CMA	Computational Methods and Applications
TT-CS	Computational Semiotics
TT-CSP	Communication and Signal Processing
TT-EA	Electromagnetics and Antennas
TT-EAH	Engineering Applications and Health
TT-EDC	Electron Devices and Circuits
TT-EES	Education and Engineering Skills development
TT-EIR	Energy and ICT for rural areas
TT-EM	Engineering Management
TT-EPS	Energy and Power Systems
TT-IM	Instrumentation and Measurement
TT-LEO	Lasers and Electro-Optic Systems
TT-MCA	Mobile Computing and Applications for ICT
TT-MEM	Micro-Electro-Mechanical Systems (MEMS)
TT-MS	Modeling and Simulation
TT-PED	Power Electronics and Drives

Network Layer Based Redundancy for Time-Critical VoIP Applications

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***Abstract*–Voice over Internet Protocol (VoIP) applications are making their way into safety-critical environments. If voice data has to be transmitted in such environments, the connection must not fail and the network has to recover quickly. Additionally, the use of specialized systems that are tailored to a certain application is not a preferred solution. Instead, the use of commercial-off-the-shelf (COTS) hard- and software is required. This paper discusses the use of standardized hard- and software as well as network protocols to allow failover times within the range of milliseconds. A redundant end-system and its network coupling are presented. The Layer 3 protocol OSPF and the combination of OSPF with the protocol-independent Hello protocol BFD are investigated to fulfill the requirements. The tests and the achieved results show a significant reduction of the convergence time.**

Keywords–High Availability, Reliability, VoIP, Communication Systems, Network Protocols, COTS

I. INTRODUCTION

Within the last years, Voice over Internet Protocol (VoIP) more and more replaces older analog and digital circuit-switched communication technologies. Due to the use of the Internet Protocol (IP) network not only for voice communication but also for video data and numerous additional services, advantages for companies, which extend their Public Switch Telephone Network (PSTN) by VoIP can be achieved. Additionally, the Internet coverage and bandwidth increase pushes VoIP forward, both for private and commercial Internet users.

Even more, current VoIP technology makes its entrance in safety-critical communication applications like emergency call systems. Hence, not only network security but also availability [1] issues arise. VoIP operates on the base of IP networks and therefore, on the base of routers, switches, and gateways. If a node or link failure results in a communication breakdown, a new path between two end-systems has to be found within the range of a few milliseconds, otherwise the stream of voice data is interrupted significantly. Therefore the underlying network has to reconfigure itself straight away. Even static routing algorithms can be an appropriate solution for this problem, the maintenance complexity decreases by using dynamical routing technologies. Common Layer 2 and Layer 3 network protocols like Spanning Tree Protocol (STP), Rapid Spanning Tree Protocol (RSTP) [2], Link Aggregation Control Protocol (LACP) [3], Intermediate System to Intermediate System (IS-IS) [4], or Open Shortest Path First (OSPF) [5] are used in networks. However, in such networks a failover time of some seconds or nearly a minute seems to be sufficient.

This paper takes a look at the OSPF routing protocol and the routing protocol-independent Hello protocol Bidirectional Forwarding Detection (BFD). In a network topology using Commercial-off-the-shelf (COTS) Layer 2 and Layer 3 hardware (without modifying the onboard software) its use for time-critical VoIP applications is verified in this paper. Actually, recovery times of single link segments are not important, the relevant time is the duration of communication failure between two end-systems. The switching time within the networks between the end-systems is not within the scope of this paper. A system that has the above mentioned properties is expected to fit the requirements for highly available networks, which reach failover times down to the range of a few milliseconds based on well-priced hardware components.

II. STATE OF THE ART

Eurocontrol, the European Organization for the Safety of Air Navigation, specifies frameworks for highly reliable voice communication systems, which are sufficient for our work. A highly available system must be available 99,999 percent of the time [1] – which would account for five minutes of downtime per year. Furthermore, a single interruption should not last longer than 200 ms – therefore it is not enough to construct a highly available system, the failover has to be accomplished within a specific time, too.

The goal is therefore to achieve a sub-second convergence time in case of failure – the load data which is assumed to be very small in contrast to the available bandwidth is not seen as a critical issue.

The Institute of Electrical and Electronics Engineers (IEEE) and the Internet Engineering Task Force (IETF) define standards for protocols that allow adding redundant paths to networks.

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While the IEEE deals with Open Systems Interconnection (OSI) Layer 2 protocols (i.e. Link Layer protocols), the IETF elaborates standards for Layer 3 protocols (i.e. Network Layer protocols).

Starting with Layer 2, 802.1w RSTP and 802.1ad LACP are specified. The aim of a sub-second convergence time is out of range for RSTP and LACP in the required network topologies caused by a number of timing parameters, which have one second as a minimum value [6]. While in RSTP a redundant link is deactivated (until it is actually needed), LACP uses all links for data transfer and groups links between ports on different switches into Link Aggregation Groups (LAGs) to add hardware redundancy. Therefore, the data transfer will only break down in case of a failure of the complete LAG. However, the use of LAGs involves the use of a proprietary stacking mechanism.

Currently, effort is also put into developing fault tolerant industrial Ethernets commonly based on ring topologies. The path selection is based on standardized protocols like RSTP or Resilient Packet Ring [7] on the one hand and proprietary but similar protocols like HiPER-Ring [8] or Ethernet Automatic Protection Switching (EAPS) [9] on the other hand. A convergence time below one second is possible. However, the hardware that is required cannot be seen as common and well-priced nowadays.

Going one layer up it is worth to study the OSPF and the IS-IS protocol which are of the same routing protocol type. They both support BFD [10, Section III/B]. Although BFD is still a draft, it is expected to be released as an RFC in the near future. BFD provides redundancy using Layer 3 functionality. Both routing protocols have almost identical routing protocol concepts like the protocol type, algorithms and timing behavior.

Alternative approaches are the transmission of duplicated data streams as shown in [11, 12]. However, for safety-critical applications the redundancy of Real-time Transport Protocol (RTP) data packets will not fulfill the requirements; instead the physical channels have to be constructed redundant, too.

Fig. 1 shows the logical connection of different sites over a commercial Wide Area Network (WAN). The network topology assumes a redundant provider access using two Customer Edge (CE) routers and two routers under provider control. The usage of separate routers for provider and customer allows the implementation of Virtual Private Networks (VPNs), Service Level Agreement (SLA) monitoring and the coupling to already existing IP networks. Security considerations are also taken into account. The network architecture allows building a transparent software solution in the end-system which is independent of the IP addressing plan of the provider or a future provider change. The system in Fig. 1 has been tested by using OSPF and BFD. The following section presents a proposed access network scenario and a case study of mechanisms to decrease the convergence time.

III. Access Network Case Study

The access network is designed to support a safety node which runs safety-critical applications – for example voice communication using RTP streams. Two systems of identical design run in warm standby mode. Both nodes communicate through heartbeat messages, which inform each other about the proper operation of the partner. In case of failure the backup end-system takes over all services of the master end-system and transfers incoming streams to the IP subnets shown in Fig. 1 (i.e. from SITE-1 to SITE-2 or SITE-3 to SITE-4, respectively). This network architecture allows coupling of highly available networks with commercial networks of lower availability by using redundant network access (see Fig. 1) to keep the overall system availability at a high level.

Each half of the end-system is independent of each other and connected to two different subnets realized as virtual Local Area Networks (LANs) with the customer router. The end-system itself is running a specially adopted Linux operating system with Quagga [13] routing software installed. The voice communication application is communicating via a virtual loopback interface with the Quagga routing daemon and is hence independent of changes in the access network topology. The access network at all connects locations form a hierarchically designed OSPF network.

A. Open Shortest Path First

OSPF is characterized as a link state routing protocol for large scale networks using bandwidth as the main routing metric. Protocol and timer implementation of OSPF yields a long convergence time in the range of a few seconds [14].

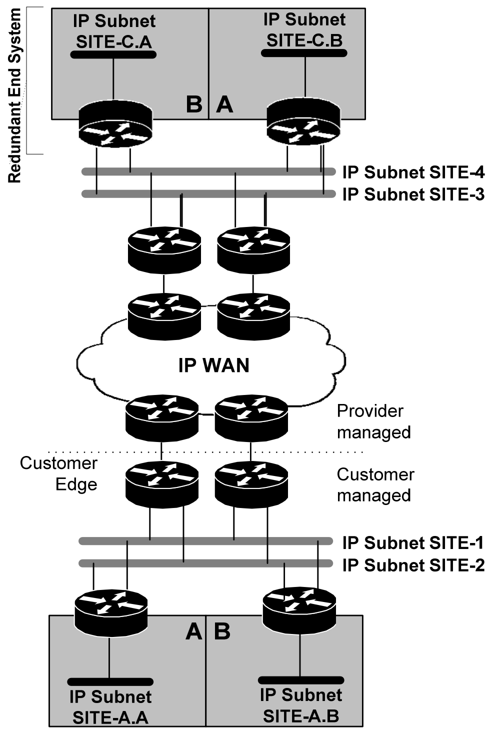

Figure 1 Redundant WAN access network topology for time-critical VoIP applications

Routing updates are propagated by the use of Link State Advertisements (LSA) packets which are triggered on any detected network change or at periodic long intervals for link-state database refresh. To start the exchange of routing updates the establishment of bidirectional communication in form of neighbor adjacency is required. On multi-access broadcast networks two additional roles exist in form of a designated and backup designated router which are automatically elected. On such networks adjacencies are established only to these routers. The routers are maintained by flooding Link State Updates (LSUs) which include LSAs under change. This flooding keeps the Link State Database (LSDB) synchronized. Using the Shortest Path First (SPF) algorithm the Routing Information Base (RIB) is built from entries inside the LSDB.

In OSPF the time to restore the traffic flow depends on the time

- to detect the link failure.
- to calculate an alternate route using SPF.
- to propagate the LSA through the network.
- to update the hard- and software routing tables.

The detection of link failures is achieved by using the network interface card hardware or the expiration of timers (dead interval, default 3 seconds) using a software based liveness detection mechanism. Link-level detection is the fastest way but often when no point-to-point link exists (as, for example, in a switched network as shown in Fig. 1) the Hello protocol (periodic exchange of Hello messages) is used instead.

The investigation on sub-second Hello timers and as a consequence sub-second convergence time is shown to be possible [14, 15], but not a possibility when using COTS hardware. Currently, there are different opinions about routing instability caused by Hello timers in the range of milliseconds. Therefore, a special investigation for each application field is required.

Some vendors offer the possibility to configure a dead time of one second with an adjustable number of Hello packets within this interval. The Hello interval is decreased by this feature but the dead interval itself is still one second. A reduction of the dead interval below one second is not possible without rewriting the routing software source code. This makes the convergence time faster than with pure OSPF but is not sufficient for the project goal of sub-second timing constraints.

To increase the stability of OSPF in large scale networks OSPF holddown (default 10 seconds) and SPF delay timers (default 5 seconds) are implemented. To avoid too frequent SPF calculations the SPF holddown timer specifies the time between two successive SPF calculations. The delay timer specifies the time between the arrival of the first update and the start of the SPF calculation and forces the router to collect LSAs for a defined time and kick off the calculation for all changes at once. Both timers can introduce an additional increase in convergence time. Setting the timers to zero will cause the deactivation of all protection mechanisms against network anomalies like, for example, link or route flapping.

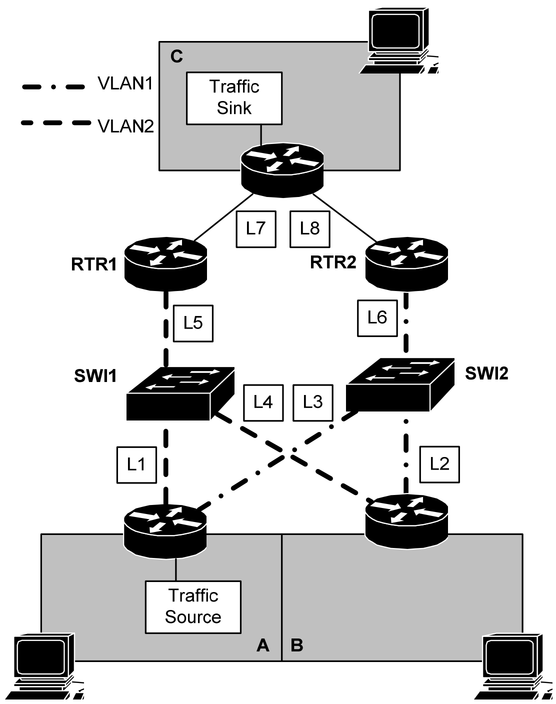

Figure 2 OSPF and BFD measurement topology

This problem is covered by the usage of adaptive SPF delay [16] which uses an exponential back off algorithm. Cisco and Open Source Quagga implemented this feature which decreases the failover time to the range of milliseconds (see Tab. 1) and also keeps OSPF protection. A dependency on Hello and Dead timers is still given which prevents the sub-second timing constraint in all required scenarios presented in Section IV.

B. *Bidirectional Forwarding Detection*

BFD is a service which reacts sensitive to transmission delays of the media stream. It uses the connectionless and unreliable User Datagram Protocol (UDP) as transmission protocol. Failures in voice transmission which result from downtimes of the underlying network layers represent the main issues for the quality of speech transmission and require a fast detection. Link failure detection varies widely on the physical media and the Layer 2 encapsulation (or the Layer 3 routing protocol) and generally leaves room for improvement. Because the keep alive mechanism that is standardized for the Ethernet physical layer only checks the electrical integrity of the interface connection without looking at bidirectional communication, upper layer protocols have to take care of this task. Layer 3 protocols like OSPF, Border Gateway Protocol (BGP) or IS-IS include their own link failure detection. Unfortunately, they generally suffer from poor failure detection speed and implement their mechanisms in software. In addition, a Layer 2 switch that connects two neighbors running a Layer 3 protocol (e. g. Fig. 2 Traffic Source – Switch SW1 – Router RTR1) hides possible link breakdowns to one of the end-systems (therefore failure of Layer 1 is not detected by RTR1). Layer 2 switches cause Layer 3 protocols to fall back to detecting failures by their Hello protocol – which results in dependency on Hello timers in the range of one second. In the presented scenario the use of the mentioned Layer 3 protocols does not provide the required sub-second detection times (see also Section IV).

Hence, the IETF launched a draft in 2004, which deals with these issues – the BFD protocol. Actually, the draft is specified in version 8 [10] and will be subsequently released as an RFC. BFD has been developed for checking connectivity in the forwarding path across multiple network hops and tunnels. Theoretically, BFD can be used for protocols in Layer 2 and Layer 3 as well as IPv4 and IPv6 networks. Manufacturers of network devices support BFD for Layer 3 protocols only. The reason why BFD requires the support of underlying network protocols – routing protocols in Layer 3 – bases on its functional principles.

If BFD detects a link failure, an additional routing protocol has to take care for making use of this information. BFD is a protocol-independent Hello protocol. It detects potential neighbors by querying the underlying routing protocol. In case of success it starts to initialize a BFD session by a three way handshake using BFD control packets. During this process the device will run through down-, init-, and up- states. When the session has been established the BFD protocol starts to exchange BFD control packets with its session partner by the use of UDP. If shared media is used in the network the communication between two neighbors is run in unicast mode. As opposed to Hello protocols implemented in common routing protocols, BFD supports a Hello interval, which defines the time period between sending BFD control messages in the range of a few milliseconds. A neighbor is declared to be down after a specified amount of BFD control packets has not been received. Reducing the Hello timer far below the minimum timer values that are defined by the manufacturer may cause higher jitter of the detection time and an increased failure probability by erroneously declaring a node as down, but will not automatically result in lower failure detection times [17]. This limitation is influenced by the hardware that is used for the network devices and can be in the range of 5-50 ms [18]. If BFD is realized in software the Hello timer is settled at the top of this range.

The BFD protocol specifies two operating modes – entitled as asynchronous mode and demand mode – which differ in the communication procedure between the partners. A system that operates in asynchronous mode regularly sends BFD messages within the predefined period of time. Otherwise, in demand mode it will only initialize this transmission in case a verification of connectivity is explicitly required. The demand mode is specified to operate simultaneously or independently in each direction. Additionally, an Echo function is specified for both modes. Received BFD Echo packets are looped back to the transmitting neighbor without a change – if a number of Echo packets are lost the session will be declared to be down. The use of BFD tends to be a promising method to boost the convergence time of a system like the one shown in Fig. 2.

IV. RESULTS

Measurement results are obtained by using the network topology in Fig. 2. The behavior of the access network is investigated by exposing it to different link and device errors on the network. The access network for voice communication stays separated from others. Therefore, the paper focuses on unexpected network failures and not on the influence by other traffic sources. The two customer edge routers (RTR1/2 Model Cisco 1841) are connected via Layer 2 Switches (Dell Powerconnect 3424) with the redundant end-system (A/B) using Quagga as OSPF routing daemon. Switches are required to support multiple nodes at a site. All experiments are performed using Linux kernel 2.6.20 and Quagga 0.99.9 on the Linux end-system.

Quagga uses the Linux routing subsystem. Linux routing is designed to handle multiple routing daemons concurrently. Linux uses a delay timer (default 2 s) before the route cache is flushed or updated. A flush operation of the routing table is very costly and should be avoided or done at longer intervals to prevent overload situations for the kernel. The delay timer has direct influence on the convergence time: it increases the value of the delay timer on each routing table change event. For the measurements the delay is disabled. Protection is done by protocol functionality implemented in Quagga which is responsible for updating the routing table. Stability considerations have to be done in a network with a high prefix count. A higher number of changes which result in lots of re-configuration events will yield to increased timing values. The results show that the required convergence time will stay far below 1 second.

In order to execute a sufficient number of test runs, the link failures were not manually initialized. A device, called the link-cutter, is connected in series between two nodes through network cables. The link-cutter is able to generate dynamic as well as static influences on 100MBit-network 100TX-RJ45 cables. The crucial property of the link-cutter is to directly influence the physical layer by, e. g. physically disconnecting a link using relays. The goal is to investigate the influence of different cable failures on the network protocols. For these test runs the link-cutter is used for automatically and periodically separating and re-connecting two nodes by cutting their connection.

The measurements are performed in two different test cases. The first test case investigates the failover using OSPF with all features enabled to accelerate the convergence time described in Section III/A. The second test case extends the configuration with the BFD protocol described in Section III/B. Link- and node failures are simulated on one hand by shutting down ports and reloading or switching off network devices on the other hand by using the link cutter device. For test runs, SIP sessions are established and RTP voice streams are submitted between traffic source and traffic sink. The defined test cases and the achieved results are listed in Tab. 1. The values represent the time required to set up a new working communication path using UDP protocol after an error occurred.

The results for the pure OSPF configuration show that the failover is fulfilling the required timing constraints wherever direct link status detection is possible. The tuning of SPF and LSA timers accomplished this. A nearly instant flooding of LSA messages keeps the router switching to the alternate path instantly. Problematic cases are failures where the sending node relies on the expiration on the dead interval to declare neighbors dead. This value can also be interpreted as the length of voice stream interruption during a call.

These test cases can be improved by using BFD as an addition to the OSPF Hello protocol. The BFD implementation on current Cisco firmware is also rudimentarily supported by a special kernel module called KBFD [19] with Quagga using Linux. This module was used for testing after modifying it for stability and correctness of the BFD functionality. The BFD

TABLE 1 OSPF/BFD MEASUREMENT RESULTS

	Link/Device	OSPF [s]	BFD [s]
Link Failure	L2 L3 L6 L8	0.005 0.040 **1.035** 0.060	0.005 0.040 **0.171** 0.060
Device Failure	RTR2 SWI2	**0.980** 0.050	**0.161** 0.050

module is communicating via the Linux Netlink kernel interface with the Quagga routing daemon. The nodes RTR1, RTR2 and also the end-system use the asynchronous BFD mode without using the echo function. A convergence time far below one second is achieved for the access network for each tested failure. The limiting factor for the convergence time is the minimal receiving and transmitting interval of 50 ms on the Cisco router. To assure reliable failure detection a minimum of 3 BFD control packets should be allowed to miss before declaring a router as dead. The aeronautics communication panel poses that the VoIP packet loss must meet the requirement of a maximum of 150 ms [20]. The above presented results exceed this limit, but further modification of timing parameters may show improvements (not implemented in COTS now). Other approaches mentioned in [11, 12] can be used in parallel. Further investigation has to be done to figure out stability consequences as a result of the short intervals also considering the public provider network connecting different sites.

V. CONCLUSION

This paper presents the design of an access network which supports highly available end-systems and runs safety-critical applications. A combination of Open Source routing software in combination with COTS hardware routers and switches are used to create a cheap and generic site topology. A sub-second convergence time is possible with features in common OSPF implementations of different manufacturers but only with restrictions. OSPF in combination with BFD allows a sub-second convergence time also in network topologies where direct link detection is not possible and should be the preferred way. A worst case convergence time below 200 ms is achievable for link and device failures in the introduced access network.

Extensions to this study are planned in multiple ways. The first step is to discuss the influence of the provider network. Different studies exist in the topic of OSPF stability and convergence in large IP networks. Simulations should be used to extend these results by the general usage of BFD for link detection. Also statements about stability should be worked out. The usage of COTS hardware with their current software implementations and limitations will stay a framework requirement.

A second step will be the discussion of extending the use of BFD as a protocol between routers to an end-to-end failure detection mechanism. BFD – on its way to become an RFC – allows the implementation of a single liveness detection mechanism through the complete network topology supporting single-hop, multiple-hop but also end-to-end scenarios. The implementation of BFD in software and not as part of the forwarding plane as primarily intended will raise new questions about achievable speed and jitter.

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