Real Time Switching for Operational Resource Reduction in Live to Virtual Communications

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ABSTRACT

Existing bridging technologies such as Live Radio Bridges (LRB) and Virtual Tactical Bridges (VTB) successfully exchange transmissions between live and virtual communications assets. However, these technologies require a dedicated operational radio to serve as a relay for each circuit bridged. The one-to-one relationship between an operational relay and bridged circuit, in conjunction with the associated costs and restricted availability of operational radios, continues to constrain exercise planners. A two-year research effort, conducted by the Concept Development and Integration Laboratory (CDIL) at the Naval Air Warfare Center Training Systems Division (NAWCTSD) in Orlando, Florida, has resulted in the development of advanced capacity prediction methodologies coupled to a prototype Integrated Live to Virtual Communications Server (ILVCS). The ILVCS serves to reduce the operational resources required to bridge live and virtual communications during a Live, Virtual, Constructive (LVC) training event by utilizing a single relay for multiple bridged circuits. This paper will discuss the systems used to address issues such as latency, degradation and loss while allowing for real time control and switching of communications resources. Topics discussed will include techniques for achieving acceptable latency in live to virtual communications, hardware requirements for transceiver switch timing and radio frequency (RF) monitoring, and software requirements for real time control and management of the operational resources required to bridge live and virtual communications.

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INTRODUCTION

The Concept Development and Integration Laboratory (CDIL) at the Naval Air Warfare Center Training Systems Division (NAWCTSD) developed a prototype Live to Virtual Communications Server, or ILVCS. This device serves to reduce the operational resources required to bridge live and virtual communications during a Live, Virtual, Constructive (LVC) training event by utilizing a single relay/trunk device for multiple bridged circuits. The nature of this real time communications – trunking style – technology requires that transmissions are detected and relayed cleanly between virtual and live realms within acceptable measures of latency, loss, and degradation. This paper will discuss systems used to address these issues while allowing for real time control and switching of communications resources.

Before the ILVCS technologies are discussed in detail, it is important that a brief history of LVC training is discussed and the role of the ILVCS is defined.

The History of Live to Virtual Communications

The Tactical Advanced Combat Direction Electronic Warfare (TACDEW) training system served as one of the pioneering LVC training systems in the late 1970's. The communication system integrated LVC components to support distributed training needs identified by the U.S. Navy. At the core of the TACDEW communication system was the Multi-Unit Tactical Training System (MUTTS) which provided an interface between the analog (live) and digital (virtual) domains (Lackey, Sprague, Kotick & Malone, 2007).

The Live Radio Bridge

As LVC training systems advanced, so did the live-to-virtual (LV) communication systems used to connect them. Live Radio Bridging (LRB) enables live radio frequency (RF) communications to be integrated with virtual radio digital communications. A single LRB is comprised of a software application residing on a networked personal computer (PC) that is physically paired with an operational radio that serves as a relay asset. Transmissions passed between the live and virtual domains are translated from RF to digital, and vice versa by the LRB. Thus, live radio operators and virtual radio operators may communicate with one another if they are tuned to the same frequency, regardless of the type of radio they possess.

The Virtual Tactical Bridge

LRB technology functionally satisfies integration of LV communications, but requires a dedicated relay radio for each LRB PC. The Virtual Tactical Bridge (VTB) elevated the functionality of LRB technology by bridging up to sixteen relay radios simultaneously with one PC. However, the VTB architecture requires a relay radio to be statically allocated for each circuit to be bridged. This one-to-one match between relay radio hardware and the number of circuits to be bridged presents challenges to the LVC training community. Hundreds, possibly thousands, of relay radios may be required to support the current and envisioned Navy and Joint LVC training architectures (Lackey, et al., 2007). Moreover, integration of local law enforcement, emergency services, intelligence assets and other Homeland Defense elements will exacerbate the issue.

ILVCS Prototype

To alleviate the operational radio hardware requirements described above, a LV trunking system was developed. The prototype ILVCS reduces the number of relay/trunk radios without negatively impacting quality of service. With these improvements, and the ability to control relay radios in real time, it is imperative that the ILVCS addresses latency, loss, and degradation within the design.

THE CHALLENGES OF REAL TIME SWITCHING

With a requirement to support the shifting needs for relay resources in real time, it is important to establish a definition for real time that satisfies both the timing requirements for acceptable latency, loss, and degradation, while also arriving at a technically feasible solution. For the purposes of LVC training, real time is defined as an ability to detect, process, and pass communications traffic between live and virtual realms while maintaining acceptable latency, loss, and degradation benchmarks. To follow this definition, it is first required that such benchmarks for LVC training be established.

Acceptable Latency

One of the first, and most fundamental, technical challenges addressed by the ILVCS comes in the form of latency. Conversational speech is fundamentally driven by the effects of latency, and it is important that efforts are taken to minimize such effects to within acceptable parameters (Emling and Mitchell, 1963). Research on the effects of delay in telephone conversations – initiated by Bell Laboratories throughout the 1960's and 1970's – generalized that the quality of a conversation decreases as delay increases (Helder 1966). Further research at Bell Labs established some general thresholds at which delay is unacceptable (Brady, 1970). Later, the evaluation of acceptable latency was updated by the International Telecommunication Union (ITU) in creating the G.114 standard on One-Way transmission time and the underlying G.107 computational model (ITU 2003, 2005). This standard provides a baseline for acceptable latency in end-to-end one-way delay. Using this standard, noting that round trip delay can be distributed in any manner as long at the total delay adds up, it was chosen that the ILVCS shall maintain latency values below 800ms round trip.

Sources of Latency

The ILVCS exists as a bridge between live radio and virtual radio technologies and thus has to deal with translating both domains. The fundamental nature of the virtual network requires that audio communications are digitized, packetized, formatted to some standard, and sent across an IP network. Such standards could be the IEEE 1278 Distributed Interactive Simulation standard, IEEE 1516 High Level Architecture, or the ITU H.323 standards. Regardless of exact standard, they all require packetization of an audio stream for transmission across a distributed network. This packetization will inherently introduce an added latency to the audio. This packet / buffer size can be adjusted with an expense inversely proportional to network load. Although this latency can be adjusted, it is unavoidable and must be the starting point for the evaluation of latency. An additional source of latency can come from load related network delay, and the adjustable jitter buffers used to compensate in the software. The packetization of the audio stream and re-assembly into a continuous stream requires that playback of the data happens at a slower rate than the arrival of the transmission packets. If the packets are delayed due to a spike in network load, or any delay in sending the data, an additional latency may need to be added at the receiving end to ensure the output stream is not broken while waiting for new data to arrive. The use of a jitter buffer at the receiver increases latency but prevents variable delays in packet arrival from degrading the audio signal.

Sources of Loss

Loss is defined as a complete transmission failing to pass between virtual and live domains. Due to the fact that the ILVCS utilizes fewer relay radios than total communication nets in an exercise, the possibility of loss is a real issue. It is important that all possible sources for loss are addressed. The most important possible source for loss of a transmission is due to resource contention. A substantial portion of the research and development effort on the ILVCS involved the design and implementation of a resource utilization prediction algorithm based on exercise parameters (Lackey 2006). In any given exercise, the number of nets chosen for the communications plan will be some amount greater than the number of relay resources available for bridging. The limitation overcome by the ILVCS is that the possibility exists for more transmissions to exist simultaneously than there are resources to relay them.

An additional cause of resource contention can be caused by illegitimate activity or false positives. For example, improper setup of a communications plan may result in using a frequency that is shared by a local company, airport, or military base. During an exercise, activity on that frequency could trigger false detections of active transmissions and tie up resources unnecessarily. If an exercise is reaching a peak level of activity, and any spare capacity is utilized by false positive detection, the situation could result in a loss of a legitimate transmission. Other sources for false positives can come from low detection thresholds, intermodulation effects, and spurious RF emissions. Sources for these false positive can be poor antenna farm design, radio/monitor configuration, or communications plan frequency layout.

Lastly, loss of a transmission can be caused by a simple lack of detection. In the live-to-virtual direction, if improper hardware is used, or the detecting system is configured to monitor more frequencies than can be supported to maintain the real time requirement, the possibility exists that a transmission could come and go before the detection hardware is able to acknowledge its existence. Additionally, in the virtual-to-live direction, software monitoring the virtual transmissions must be capable of detecting active transmissions quickly enough to maintain the real time requirement as well.

Due to the nature of LVC training exercises, the possibility of physical harm is real for all participants. To ensure the highest level of safety, loss due to a resource unavailability or missed transmission detection is unacceptable (Lackey 2006). In addition to maintaining operational performance metrics, the live-to-virtual bridge should have some capability to determine the probability of a fault before operation and use this information to self modify or, at a minimum, notify the operator of such faults. The ILVCS implements these checks through a probe of the relay resources and initiation of a built in test (BIT) on the radios. Radio operation time beyond that of radio mean time before failure specification or failure of the BIT will result in notification to the operator and a halt in the setup procedure until such faults can be remedied. A screen shot of the ILVCS fault screen and BIT test can be seen in Figure 1.

Degradation

In addition to latency, which can be a cause of degradation, there are other characteristic changes that can happen to a signal while bridging between live and virtual domains. The ILVCS, when in operation, is reactive to the environment, and therefore, some amount of time is required to detect activity, decide what to do, act on the decision, and pass the transmission through to the other domain. This delay not only contributes to latency, as discussed earlier, but also can contribute to degradation of the signal. Delayed detection processing, relay resource down time whilst reconfiguring, and resource contention can all lead to pre- or post-clipping of the transmission signal. In fact, some pre-clipping of a transmission is guaranteed due to relay resource configuration down time and activity detection latency. Research conducted by this effort on recorded virtual radio LVC data found that the average time between a push-to-talk (PTT) and the first utterance in a transmission is approximately 330ms. It is expected that transmissions originating from the live side exhibit a >330ms delta between PTT and first utterance. As a result, a 300 ms pre-clipping degradation factor was established as the standard for acceptable pre-clipping degradation. However, post clipping is not acceptable.

Figure 1: ILVCS Reliability Dialog

Another form of degradation can come from the use or lack of use of a jitter buffer. The jitter buffer may be necessary to prevent the interruption of audio transmissions mid stream. If a jitter buffer is required, and a buffer size is chosen too small or the buffer is not used at all, the audio signal could be interrupted and important information could be misconstrued or difficult to interpret. Certain tradeoffs could be made to compensate for poor performance at the expense of added degradation. Higher compression rates for audio encoding can compensate for performance issues at the expense of possible increases in degradation of the audio signal. Current choices for audio encoding include µLaw, CVSD, GSM 06.10, GSM 06.20 Half Rate, A-Law, PCM, and VQ.

OVERCOMING REAL TIME CHALLENGES

The operation of the ILVCS is based on the ability to quickly respond to changes in communications activity and rapidly reconfigure resources to support the newly modified communications requirements. Figure 2 illustrates the transmission lifecycle. This emphasis on detection and timing requires that the hardware and software components used for detection and relaying of transmissions is capable of reacting quickly enough to meet these requirements. The following sections will discuss the various components within the ILVCS and how the design was tailored to meet the real time challenges established above.

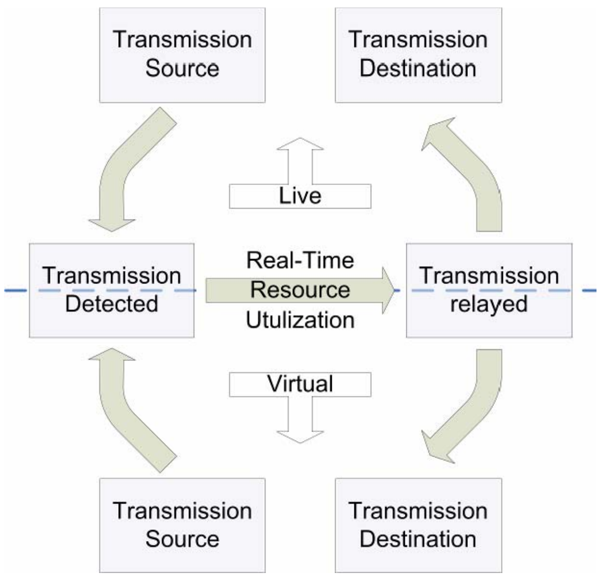

Figure 2: LVC Transmission Lifecycle

Scanning Relay Radios vs. Dedicated Scanning

During development of the ILVCS, two major methodologies emerged as feasible techniques for solving the resource trunking problem. First, it was proposed that the relay radios chosen could incorporate a scanning capability and serve as part of a collective. They would operate by monitoring for activity when not active and responding to active transmissions by temporarily acting as a relay when needed.

The second method utilized a dedicated monitoring receiver or set of receivers to act as the sole detector of live side transmissions. The radio resources would then be required only to act as relay resources in the system.

Figure 3 depicts a scanning relay scenario diagram for a simple 5 net communications plan with support for two simultaneous transmissions.

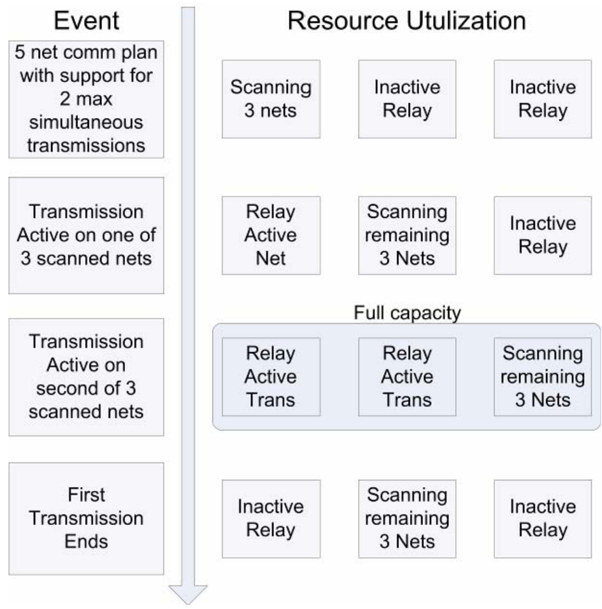

Figure 3: Scanning Relay Example Scenario

This design is heavily dependent on the ability of the scanning relay to scan, detect, communicate, reconfigure, and tune in order to output received audio quickly enough to prevent excess degradation, or even loss, of the transmission. Initial testing and development with relay candidate hardware and a discrete event simulation of the ILVCS showed that while there were no technically insurmountable challenges associated with this method, the resource cost required to support larger scaled implementations negated the resource and cost benefit fundamentally provided by the ILVCS.

As an alternative, the second method was investigated. Figure 4 illustrates the latter scenario where transmissions are handled by a dedicated scanning system. While this design does require a dedicated piece of hardware for scanning, it serves to better utilize the capabilities of the hardware and the system, thus improving both performance and efficiency.

The initial testing and simulated results verified this methodology as more scalable, higher performing, and cost effective than the alternative. The next section will discuss the challenges faced in choosing adequate performing hardware.

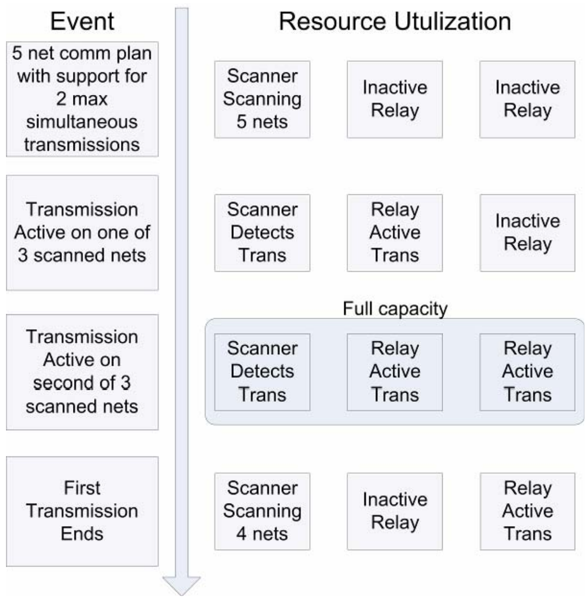

Figure 4: Dedicated Scanner Example Scenario

Scanning Hardware

The detection of live side transmissions is critical for the timely response of the system. Unlike virtual side transmissions – which, due to their existence in a digital domain, can be buffered while relay resources are being acquired – live side transmissions must be quickly monitored and detected before any buffering can take place. This requirement places a heavy burden on the hardware responsible for monitoring the RF environment. A number of scanning devices and detection paradigms can then be considered based on a set of initial criterion. First, the device needs to have a suitable interface for control and an included control capability to support the basic functionality of RF activity notification. Also, the scanning speed must be adequate to prevent loss of transmissions due to the unavailability of the device. The device must have the ability to monitor a frequency band wide enough to support the range of frequencies used for LVC events. Finally, depending on the design paradigm, the device must have the ability to detect transmissions, issue a notification remotely, and continue to scan simultaneously. With a dedicated device, used specifically for detection of RF activity, relay radios are allowed to play the singular role of relaying transmissions. The challenges of real time reconfiguration can be redirected to a specialized device with capabilities designed for this purpose. The result is a faster and more responsive real time system.

ILVCS Software

With hardware chosen and designed to meet the established requirements, it is now important that a proper software design is put in place to manage the bridge and ensure that adequate real time performance is met. The definition of real time for Live to Virtual bridging is driven by the timing requirements established in earlier sections and not by the definition of a “real time” operating system. This being the case, it is important to point out that a “real time” operating system and specialized computing hardware is not required to maintain the level of performance required for live to virtual bridging. The main bottleneck in timing falls within the realm of scanner speed and radio reconfiguration not task scheduling and execution time.

Therefore, due to the wide spread use within the Fleet and the common foundation of many technologies described above, the ILVCS was developed on a COTS PC running Microsoft Windows XP Professional. The ability to leverage existing technologies (LRB, VTB, etc.) facilitated a faster development schedule and simplified interoperability within the virtual and live domains.

The ILVCS software system is comprised of a Smart Radio Manager with graphical user interface and the Instructor Station software. The Smart Radio Manager is responsible for monitoring input from the monitoring receivers, detecting virtual side transmissions, and tuning relay radios in support of the real time bridging requirements. The Instructor Station software is controlled by the Smart Radio Manager and serves to route audio between live and virtual realms. A diagram of the software components within the system is shown in Figure 5. As the manager of the system, the Smart Radio Manager must have the ability to control both virtual side and live side interfaces. At the lowest level, the virtual and live radios are controlled via the shared memory interface to the instructor station software and high-speed serial interface to the physical radios. The Smart Radio Manager employs a LiveRadio class to assist with communication and control of an individual radio and a VirtualRadio class designed to assist with the communication and control of a virtual radio. For each circuit bridged during an exercise, there exists a VirtualRadio and LiveRadio pair individually responsible for bridging communication traffic. The individual pairs are created by the Smart Radio Manager and operate as unique processes within the system. The manager communicates with the threads through message queues thus allowing for each process to produce and handle commands without degrading the performance of the others. All operation can happen in an asynchronous manner.

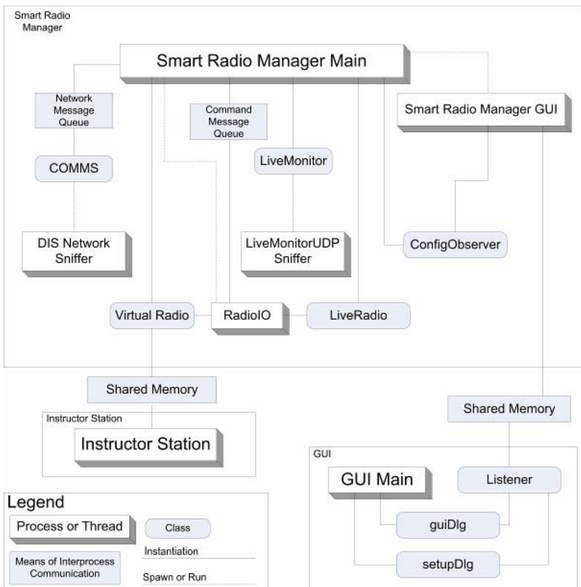

Figure 5: ILVCS Software (Lackey, et al., 2007)

The graphical user interface (GUI), shown in Figure 6 and Figure 7, allows for easy setup and configuration of the ILVCS in addition to providing feedback in the form of a status panel during operation. The graphical user interface utilizes the Microsoft Foundation Classes (MFC). The integration of MFC into the program allowed for easier integration of controls and GUI dialogs.

The ILVCS Configuration GUI contains an implementation of the Lackey optimization algorithm (Lackey 2006). This algorithm is the final component necessary to ensure the real time and loss/degradation requirements are met by the system.

Using Lackey's method, the software is able to determine the necessary number of relay radios to support the given communications plan.

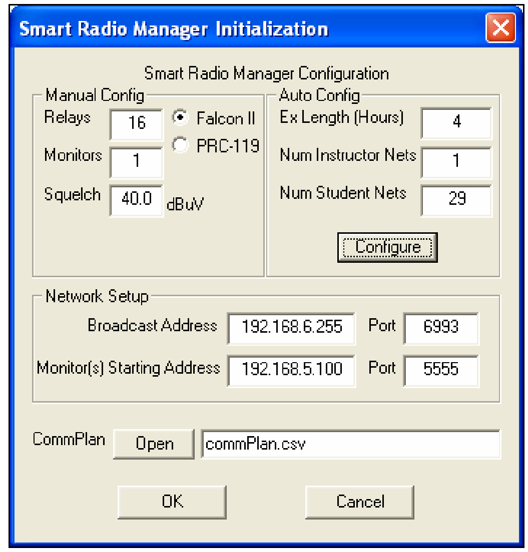

Figure 6: ILVCS Setup GUI (Lackey, et al., 2007)

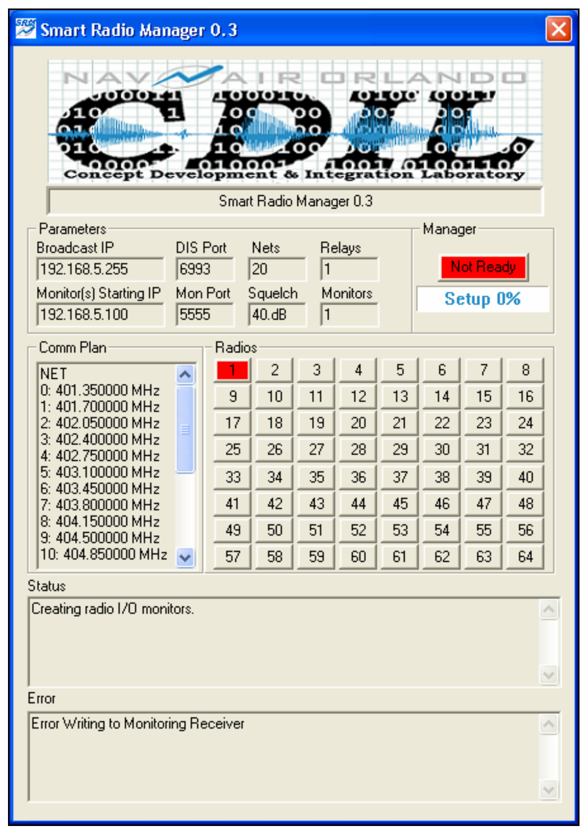

Figure 7: ILVCS Operation GUI

In general, the ILVCS software must support the timing requirements established above. In addition to supporting the real time demands, the software designer must design in support of the hardware, avoid the reinvention of the wheel through leveraging of available tools, and consider the scalability and usability of the tool. By leveraging existing tools, a Fleet supported operating system, and scalable methodologies, the ILVCS achieves this goal.

FUTURE RESEARCH

The focus of the ILVCS research was targeted at the principle of LV trunking. The prototype system was therefore designed for clear communications only. The need for a continuation of this research into secure communications and then frequency hopping is critical. The advancement from linear secure communications to plain linear communications may soon be on the horizon. The current design is capable of monitoring all RF energy and therefore, existing capabilities may be able to support secure communications trunking with little modification. A continuation of the research into secure communications should be conducted as it is the next logical step. Following success in secure communication, the challenges of frequency hopping should then be addressed. To do so, an improved monitoring system, with capabilities to detect and track a frequency hopping transition must be developed and tested.

CONCLUSION

Today's training requirements are ever changing and growing. The increasing communications channel count and investment required to support future training scenarios will continue to grow. To maintain acceptable latency, degradation, and loss benchmarks, while meeting the real time requirement defined in this paper, it is important to design hardware and software with the capabilities to meet the demand. Fundamentally, the design must be capable of reliable and rapid detection of a transmission origination from both virtual and live domains and have the capability to react and tune relay resources – both live and virtual – in real time. The ILVCS provides a means to maintain the currently established standards for reliability and risk while reducing cost and increasing capability.

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