



Transforming mission-critical communications networks

IP/MPLS network transformation for simulcast applications

Application note

Abstract

The challenge faced by public safety first responders and field personnel from utilities and transportation agencies is increasing because they are managing ever more complex situations: emergency response to accidents and natural or man-made disasters, and border and coastal control. Many of their missions require efficient and effective real-time collaboration across an area of several hundred square miles or more. To satisfy the stringent communications requirements, a simulcast solution has been deployed in many public safety agencies, transportation authorities and even utilities. As electronics and CPU power have improved, the simulcast solution has also changed from analog to digital transmission in the past 20 years, and has recently been migrating from a TDM T1/E1-based system to an IP/Ethernet-based system.

As mission-critical communications networks are rapidly adopting IP/MPLS as part of the converged network transformation program, continued support for simulcast application as it evolves is mandatory. Rising to this challenge, Nokia delivers a converged IP/MPLS-based communications solution with comprehensive synchronization capabilities and seamless microwave integration. This paper describes how this solution can be deployed to support simulcast applications with both TDM T1/E1-based and IP/Ethernet-based systems.

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Introduction

Land mobile radio in public safety

The Detroit police department first started to use Land Mobile Radio (LMR), also known as Public/Professional Mobile Radio (PMR), in 1928.¹ Since then, the technology has evolved to become a critical communications tool that must be in the hands of every first responder and member of field personnel who are responding to an emergency or accident scene.

A radio system can operate in one of the following three operation modes:

1. **Simplex mode:** One frequency is required; all transmitting mobile radios are tuned to the same transmit and receive frequency. When one radio is transmitting, all other units are able to receive directly and no LMR base station is involved, as long as they are all within the propagation range. This is also commonly known as direct mode. This mode is essential as it allows first responder to communicate with each other when outside the network coverage area.
2. **Duplex mode:** Two frequencies are required—the uplink (mobile to base station) frequency and downlink (base station to mobile) frequency. The transmitting mobile radio sends messages on the uplink frequency to the radio site, which repeats and rebroadcasts them on the downlink frequency to all other mobile radios tuned to the frequency. Since the radio transmitter at the site can transmit the signal at a higher level, the range is longer than that of simplex mode. It is also known as repeat mode.
3. **Simulcast mode:** Simulcast is an abbreviation for simultaneous broadcast. It is ideal when the system needs to cover an area of several hundred square miles or more with only a handful of radio channels. It also avoids the complexity of handoff since all radio sites in the simulcast system broadcast simultaneously at the same frequency. In essence, all participating radio sites are set up as if they were one giant transmitter in order to reach radio users across the whole area covered by the simulcast system. With multiple remote sites transmitting the signal synchronously, simulcast offers better urban high-rise and in-building area penetration, which is important for first responders, and provides scalability up to tens of channels if required. Also, with only one frequency channel, radio users can roam throughout the geographical area without having to switch channels.

Simulcast communication overview

A simulcast system has the following five components:

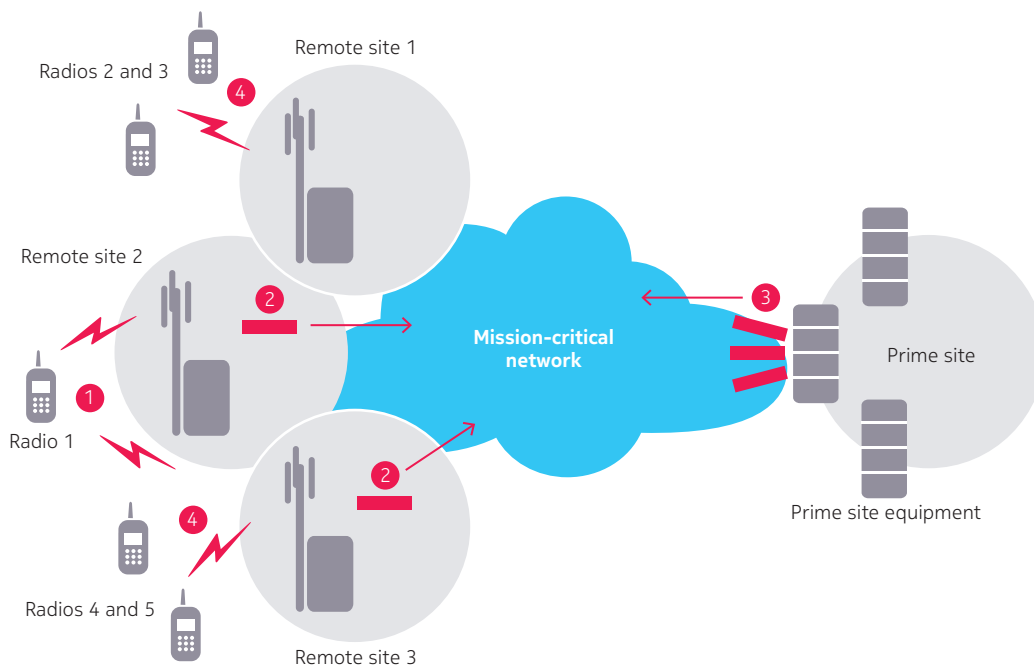
- **Master site:** Consists of computing and controlling equipment necessary to manage, configure and monitor all components in the system; typically there is an active/standby pair.
- **Prime site:** Consists of a radio base station, controller equipment (usually in a pair for redundancy protection), a comparator that votes (compares and selects) for the best radio message from the source mobile radio, and a GPS receiver
- **Remote site:** Consists of a base station and usually a GPS receiver
- **Mobile radio:** Used by first responders in the field; typically either handheld or mounted on a vehicle
- **A mission-critical WAN** interconnecting all sites

¹ T.A. Peters & L. Bell, eds., "The Handheld Library: Mobile Technology and the Librarian" (Santa Barbara: Libraries Unlimited, 2013), p. xi.

All communications take place between the radio, remote site and prime site. A high-level description of the communication procedures (see Figure 1) are as follows.

1. Radio 1, the transmitting radio, sends radio messages that are received by base stations in both remote sites 2 and 3.
2. Upon receiving the radio messages, both base stations will send the message via the WAN to the prime site to be processed and compared.
3. After the prime site comparator compares the two copies and votes for the best copy, it will send the messages to all remote sites (remote sites 1, 2 and 3 in this example) in the simulcast subsystem.
4. All remote sites will broadcast the messages over the air simultaneously to all radios tuned to the frequency. It is pivotal that they need to be broadcasted simultaneously to avoid out-of-phase signal interference. It is important to note that all users in the area will be able to listen in and beware of the latest situation, hence fostering close collaboration.

Figure 1. Simulcast system



Nokia IP/MPLS network solutions

Many operators of mission-critical networks have started to consider deploying, or have already deployed, converged next-generation networks to support all their communications needs. However, not all next-generation solutions are appropriate. To simultaneously support all mission-critical and non-mission-critical traffic, an IP/MPLS-based communications network is needed.

Non-MPLS-based IP networks have grown significantly in recent years, but they often lack the necessary traffic management capability to support traffic that requires strict quality of service (QoS) for mission-critical operations. They also lack the flexibility to optimize the use of network resources and the capability to react to network events fast enough to guarantee end-to-end QoS per application.

By using an Nokia IP/MPLS network, operators get the best of both worlds—the versatility of an IP network and the predictability of a circuit-based network along with high capacity and support for packet-based traffic with high QoS. An IP/MPLS network enables the deployment of new IP/Ethernet applications and also supports existing TDM-based applications. Because IP/MPLS networks can continue to carry existing TDM services, operators can now flexibly choose when to migrate the applications from TDM to IP.

With an IP/MPLS network, operators have a network with the following features:

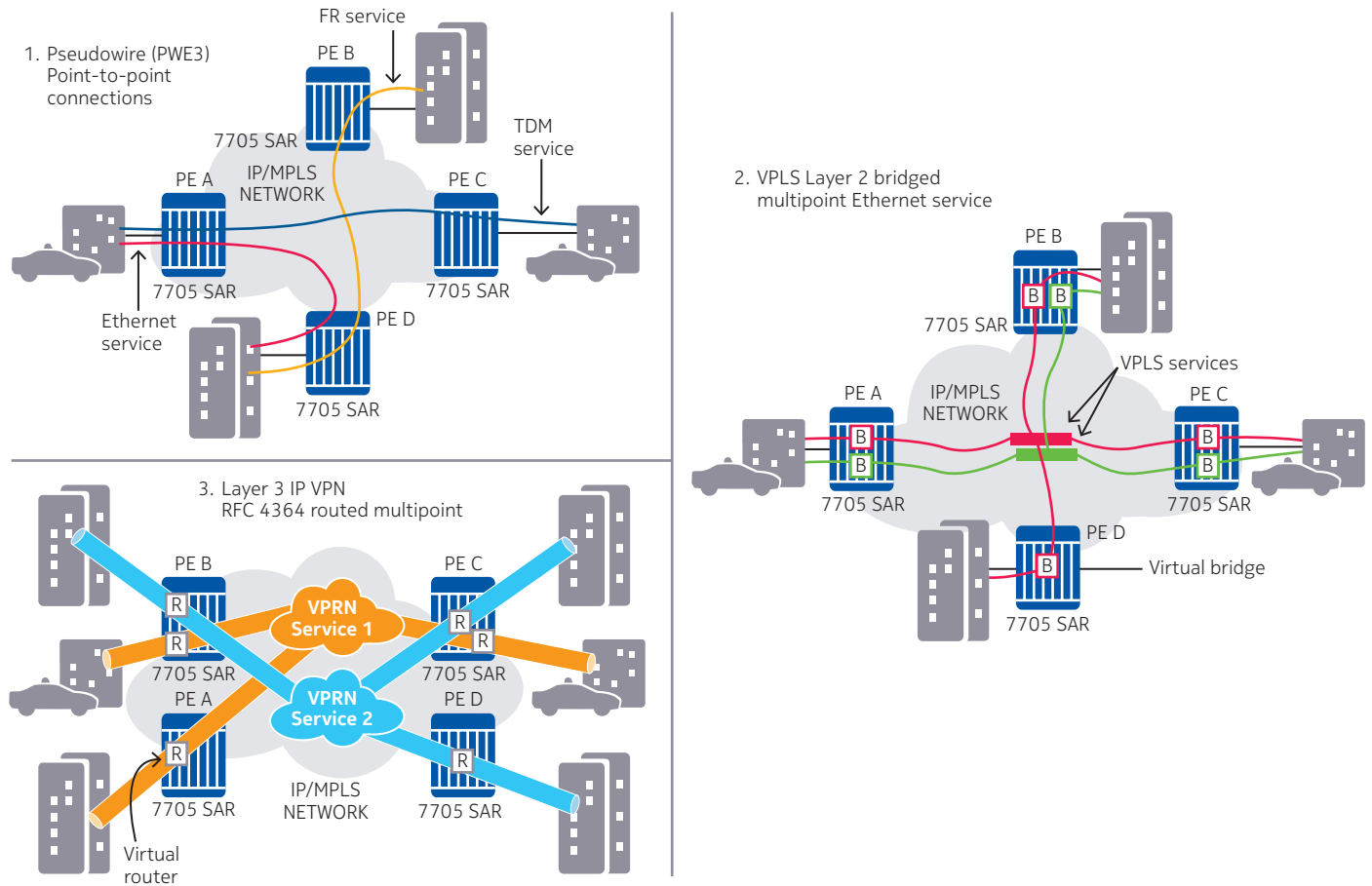
- High scalability and robustness with full redundancy and rapid recovery mechanism such as MPLS Fast Reroute (FRR)
- A solution that addresses a wide range of QoS and service level agreement (SLA) requirements, from circuit emulation to best-effort Internet surfing
- Optimized bandwidth usage of all links and avoidance of common path through traffic engineering
- An extensive operations, administration and maintenance (OA&M) suite for performance monitoring, troubleshooting and maintenance at all protocol layers
- Advanced network and service management to simplify operations

Each application that runs on the network has its unique requirements for bandwidth, QoS and availability. An IP/MPLS network enables operators to configure service parameters for each service and traffic type according to operational requirements. This includes multiple types of voice, video and data traffic. The network can also provide low jitter and delay performance to handle all traffic types effectively and reliably in real time. In addition, an Nokia IP/MPLS network supports advanced capabilities, including non-stop routing, non-stop services and FRR, to maintain high network resiliency.

Many VPNS, one network

An Nokia IP/MPLS network provides for the virtual isolation of various traffic types on a single infrastructure supporting many Virtual Private Networks (VPNs) simultaneously. As shown in Figure 2, whether the network is a Virtual Leased Line (VLL) of various types, Virtual Private LAN Service (VPLS) or a Virtual Private Routed Network (VPRN), deploying Nokia IP/MPLS allows full separation of control and data traffic in each VPN from different applications or operations in the network. The results are a fully secured environment, effective infrastructure sharing and optimal bandwidth allocation. With this advanced capability, the same IP/MPLS network infrastructure can be leveraged to carry corporate business data as well.

Figure 2. Nokia IP/MPLS network



Nokia IP/MPLS solution components overview

The Nokia IP/MPLS implementation provides a service-oriented approach that focuses on service scalability and quality as well as per-service OA&M. A service-aware infrastructure enables the operator to tailor services such as mission-critical applications so that the network has the guaranteed bandwidth to meet peak requirements. The Nokia service routers support IP routing and switching, which enables the network to support real-time Layer 2 and Layer 3 applications.

The Nokia converged IP/MPLS network leverages multiple state-of-the-art technologies. The network extends IP/MPLS capabilities from the core to access and can include the following main components:

- Nokia 7750 Service Router (SR)
- Nokia 7705 Service Aggregation Router (SAR)
- Nokia 7450 Ethernet Services Switch (ESS)
- Nokia 7210 Service Access Switch (SAS)
- Nokia 9500 Microwave Packet Radio (MPR) providing packet microwave link connecting MPLS nodes
- Nokia 1830 Photonic Service Switch (PSS) as optical layer underlying the IP/MPLS network
- Nokia 5620 Service Aware Manager (SAM) for service and network management

The Nokia IP/MPLS solution for simulcast

From a network deployment standpoint, there are two kinds of simulcast system:

1. TDM-based simulcast system with T1/E1 network connectivity
2. IP-based simulcast system with Ethernet network connectivity

Figure 3a. T1/E1 TDM-based simulcast



Figure 3b. Ethernet-based simulcast system



General communication requirements for simulcast applications

High network resiliency

In a mission-critical network carrying a simulcast application, it is of uppermost concern that the communication service remains on all the time so that first responders, other field personnel and dispatch center are fully aware of the situation to save life and stay safe. Therefore high network resiliency is a paramount network design consideration. In a typical carrier-grade backhaul network, an aggregation ring with spur (ring-and-spoke) topology (Figure 4a) is considered to exhibit enough network robustness. If the ring node with spur attached (Node A in Figure 4a) fails, even though service served by Node B is disrupted, customer impact is limited since the spur site is usually only serving a small number of customers. However, in a mission-critical network, full coverage is usually mandated even for remote sites. A typical mission-critical network would adopt a multi-ring topology, which offers multi-path diversity elevating the service availability. Beside path diversity, it is also important that the network node also has equipment protection for its key hardware such as the control and fabric card.

Figure 4a. Ring-and-spoke topology

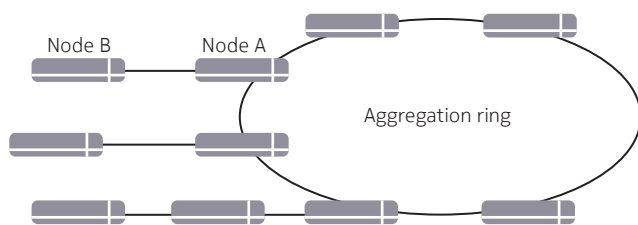
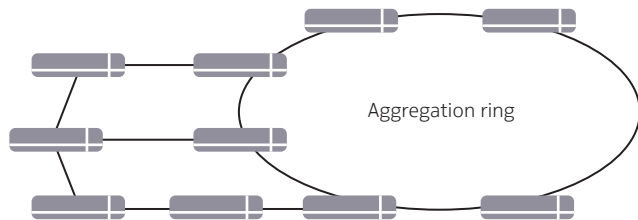


Figure 4b. Multi-ring topology



Low packet loss

Whether the network is TDM-based or IP-based simulcast, minimal packet loss is required to avoid voice quality degradation or loss of communication. With the popular deployment of microwave transmission, it is paramount that the network equipment has acute microwave awareness of the microwave link condition, for example high bit error rate and loss of frame, in order that traffic can be re-routed to preserve service integrity. On the other hand, with the use of adaptive modulation microwave transmission technology, the available bandwidth in a microwave link would change as the modulation level adapts to new atmospheric conditions. It is vital that the network equipment together with microwave radio is able to classify all traffic types, including control, synchronization, simulcast voice and other data applications, into the appropriate forwarding classes and transmit it accordingly to preserve end-to-end service integrity.

Low network delay

Simulcast is a time-sensitive, real-time application that imposes strict delay and jitter requirements on the mission-critical network. One-way, end-to-end network delay between the prime site and simulcast remote site needs to be constrained under the order of 30 milliseconds.² Another parameter to consider is the one-way, end-to-end network delay spread³ between the prime site and any simulcast remote site.

Synchronization

High-quality simulcast transmission of radio messages depends on the simultaneity of the messages by all remote sites. Therefore time synchronization among all the radios at all the sites is pivotal. Today this need is fulfilled with the on-site GPS receiver. If the simulcast system is based on T1/E1 TDM technology, frequency synchronization transport over the network is also important for accurate transmission of T1/E1, which carries simulcast information, without frame slip. There are likely also other legacy applications such as mutual aid communications and direct site-to-site orderwire communications that would require frequency synchronization as well.

An Nokia blueprint IP/MPLS solution for simulcast application

A mission-critical network solution for simulcast highly depends on various factors including:

- Network technology used by the simulcast system (TDM-based or IP-based)
- Simulcast system requirements on network delay, jitter and bit error rate
- End user's IP address and sub-netting design principle

This application note outlines a blueprint network solution based on the Nokia 7705 SAR and the Nokia 7750 SR. The 7705 SAR is deployed as the remote site router and, depending on the size of the prime and master site and interface type required, either the 7705 SAR or the 7750 SR is used there. The blueprint solution can be further tailored and refined for different deployment scenarios.

² The actual delay requirement depends on simulcast system vendor implementation and network design.

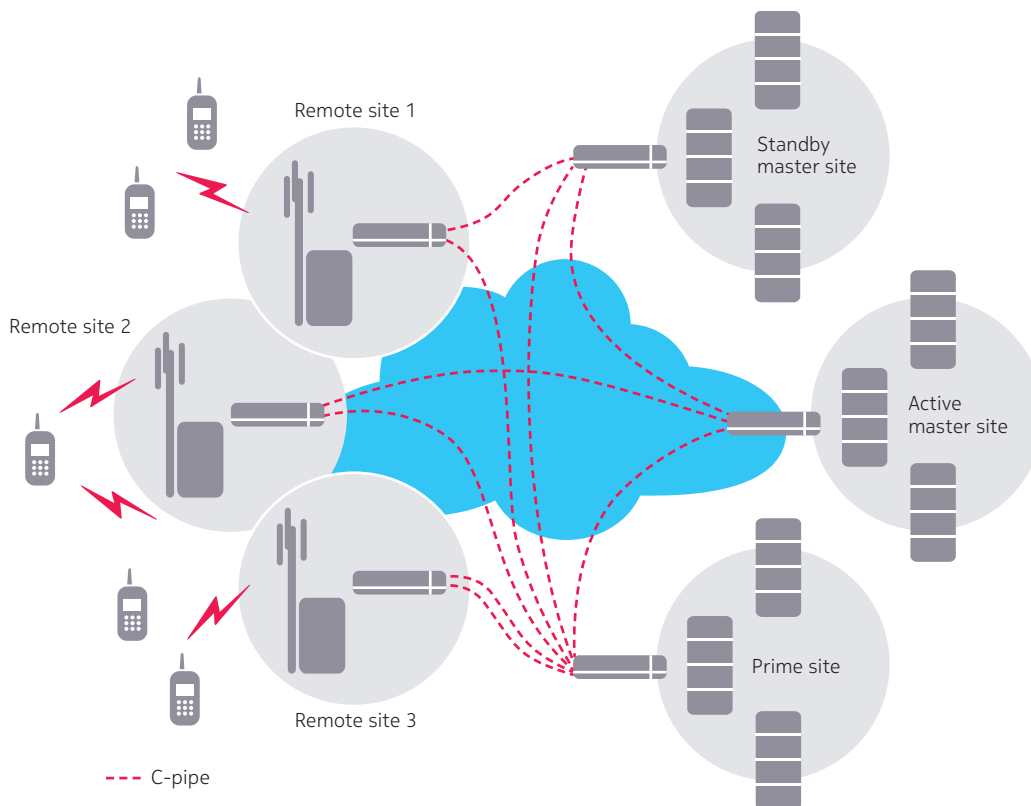
³ Delay spread is calculated by finding the difference between the prime site/farthest remote site delay and the prime site/closest remote site delay. Depending on system implementation and network design, it is typically in the order of 5 milliseconds.

Blueprint solution for TDM-based simulcast system

The following communication connectivities are required (see Figure 5):

- a) between prime site and active/standby master sites
- b) between prime site and remote sites
- c) between active and standby master sites

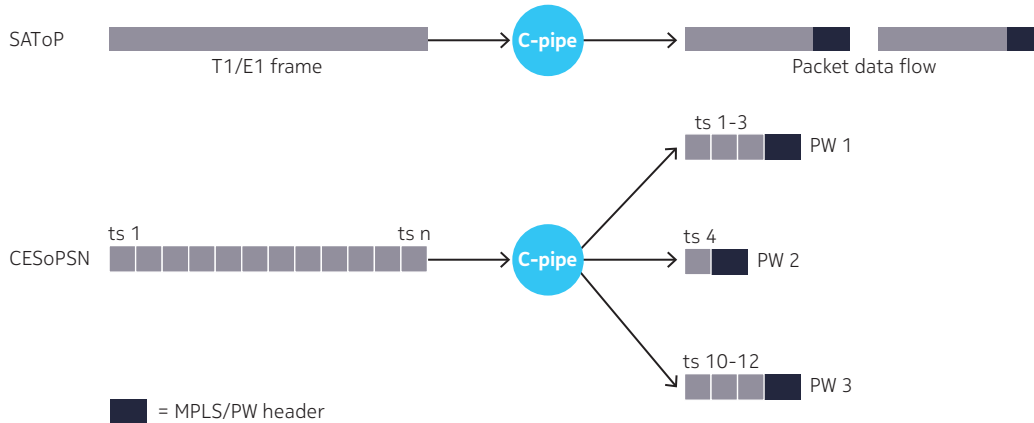
Figure 5. C-pipe-based IP/MPLS solution for TDM-based simulcast system



In the transport of TDM traffic, TDM pseudowires (PW), also called C-pipes, need to be set up among the sites individually in order to provide adequate connectivity. Depending on the TDM circuit configuration, either the Structure Agnostic TDM over Packet (SAToP) mode or Circuit Emulation Service over Packet Switched Network (CESoPSN) mode is used. When all the timeslots in a T1/E1 circuit are used, SAToP can be used as a transparent transport mechanism. When only a number of time slots are used, then CESoPSN can be used to transport only the timeslots in use (see Figure 6).

C-pipe circuit parameter configuration such as payload size and playout buffer can be optimized to fulfill delay and jitter requirements.

Figure 6. Two modes of C-pipe

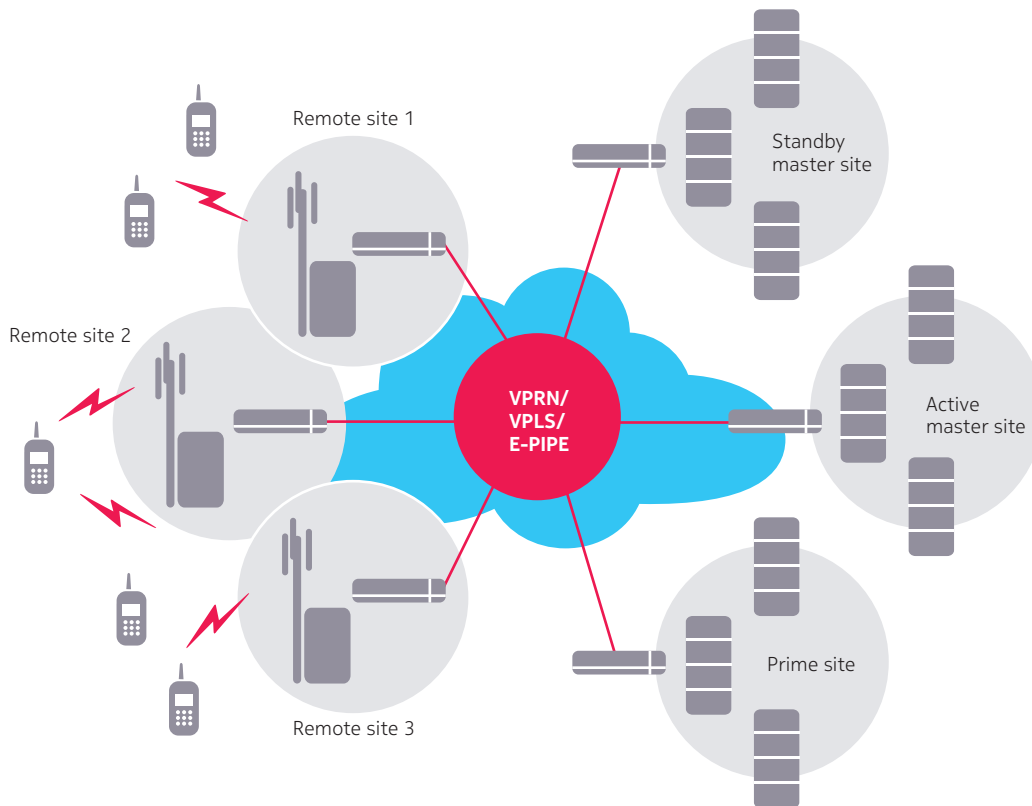


Blueprint solution for IP-based simulcast system

While connectivity among the sites remains the same as in the case for a TDM-based simulcast system, since the connecting interface to the network is now based on IP-over-Ethernet, the architecture of meshed point-to-point C-pipe connectivity can now be simplified. Only one interface circuit is required between the site simulcast equipment and the network. Flexible options are available because the IP-based traffic is carried in Ethernet packets:

- A Layer 3 VPN service—a VPRN
- A multi-point Layer 2 VPN service—VPLS
- A point-to-point Ethernet pseudowire (also known as E-pipe)
- A combination of all three

Figure 7. Layer 2/Layer 3 IP/MPLS solution for IP-based simulcast system



Synchronization consideration

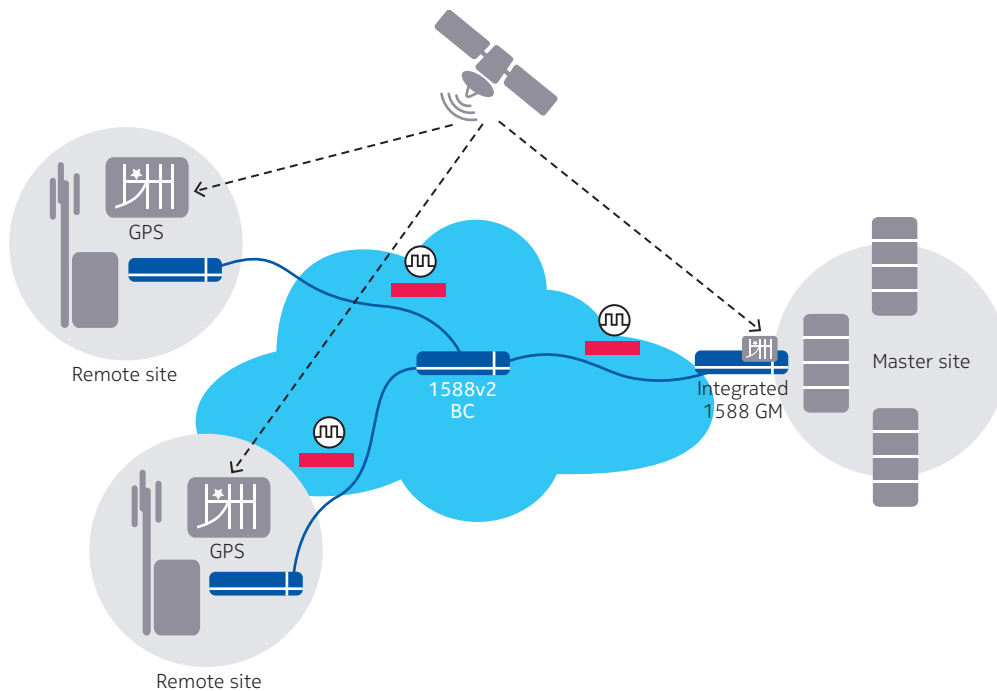
Another key aspect is network synchronization, which is particularly important for C-pipe service. While simulcast equipment at master, prime and remote sites typically includes a GPS receiver, synchronization redundancy protection is still essential to maintain the quality of simulcast transmission by all remote sites. The Nokia IP/MPLS solution can provide redundancy protection with different options including IEEE1588v2⁴ (briefed as 1588 below) and Synchronous Ethernet.⁵

The 7705 SAR at the master site can be integrated with a GPS module, becoming a 1588 grand master sending out synchronization information to the 7705 SAR at the remote sites, which acts as the 1588 slave. To ensure the quality of synchronization transported, 7705 SAR boundary clock capability, which is a combination of 1588 master and slave, is switched on to improve accuracy of the clock synchronization. It is important to utilize this capability, particularly in networks with many hops between the sites (see Figure 8). This option provides redundancy for both frequency and phase/time synchronization to remote sites. The 7705 SAR at the remote sites can also be equipped with a GPS module if necessary.

⁴ IEEE 1588v2 is a timing-over-packet technology in which timestamp information is encoded in its packets. It is also known as IEEE 1588-2008 (<http://standards.ieee.org/findstds/standard/1588-2008.html>).

⁵ Synchronous Ethernet is specified in ITU-T G.8262 (www.itu.int/rec/T-REC-G.8262) and ITU-T G.8264 (<http://www.itu.int/rec/T-REC-G.8264/en>).

Figure 8. IEEE 1588v2 providing frequency and phase/time redundancy



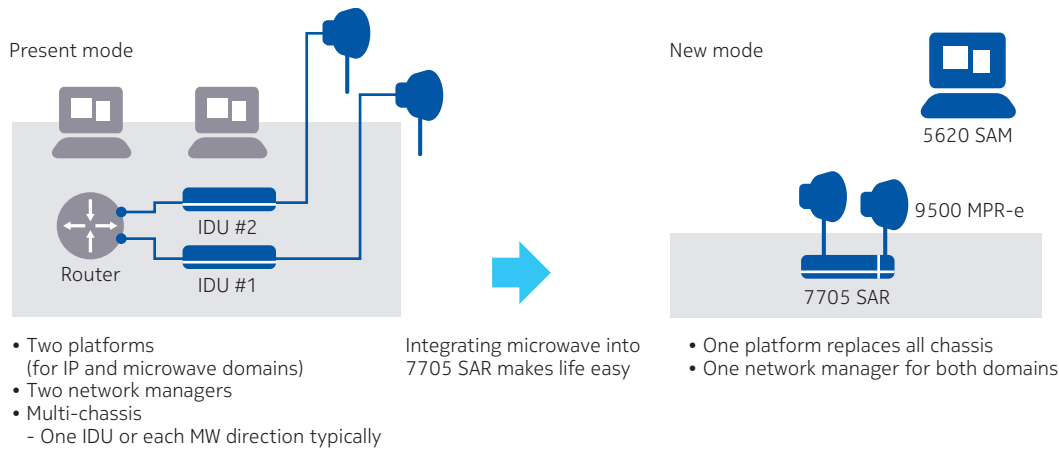
Synchronous Ethernet is another synchronization transport mechanism. However, unlike 1588, it is limited to frequency synchronization only. It works in a similar way to other physical line timing mechanisms such as SONET/SDH or T1/E1 and requires every hop in the middle to support it.

Microwave integration with IP/MPLS

With prevalent use of microwave in the mission-critical network, the seamless microwave integration of 7705 SAR with 9500 MPR-e (see Figure 9) brings immense benefits to a network that carries simulcast applications. Benefits include the following:

- Early detection of microwave link high bit error rate and other error conditions to preserve voice quality
- Convergence of multiple indoor units (IDUs) and IP/MPLS router into one platform
- High network resiliency with the full re-routing flexibility of MPLS in a multi-ring topology
- Reduced equipment space and sparing requirements, power consumption and cooling needs
- Streamlined installation and operations management
- Elimination of different network managers

Figure 9. Integrated 7705 SAR with 9500 MPR-e



A daunting task for deployment and operation

Conclusion

With public safety and other agencies migrating the backhaul networks from TDM to IP in preparation for transport of more multimedia and bandwidth-demanding applications, operators of mission-critical networks should ensure that the network solution and architecture can continue to support existing key applications such as simulcast.

The Nokia IP/MPLS network solution can help operators to extend, enhance and optimize their network flexibility and management and reduce CAPEX/OPEX without compromising safety, security or reliability. Nokia can partner with public safety and other agencies worldwide to transform end-to-end mission-critical networks.

Acronyms

CESoPSN	Circuit Emulation Service over Packet Switched Network
ESS	Ethernet Service Switch
FRR	Fast Re-Route
GPS	Global Positioning System
IEEE	Institute of Electrical and Electronics Engineers
IP/MPLS	Internet Protocol/Multiprotocol Label Switching
ITU-T	International Telecommunication Union – Standardization Sector
LMR	Land Mobile Radio
MPR	Microwave Packet Radio
OA&M	operations, administration and maintenance
PMR	Public/Professional Mobile Radio
PSS	Photonic Service Switch
PW	pseudowire
QoS	quality of service
SAM	Service Aware Manager
SAR	Service Aggregation Router
SAS	Service Access Switch
SAToP	Structure Agnostic TDM over Packet
SDH	Synchronous Digital Hierarchy
SLA	service level agreement
SONET	Synchronous Optical Network
SR	Service Router
TDM	Time Division Multiplexing
VLL	Virtual Leased Line
VPLS	Virtual Private LAN Service
VPN	Virtual Private Network
VPRN	Virtual Private Routed Network

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1. Peters, T.A. & Bell, L., eds., The Handheld Library: Mobile Technology and the Librarian (Santa Barbara: Libraries Unlimited, 2013)
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3. ITU-T G.8262, Timing characteristics of a synchronous Ethernet equipment slave clock (www.itu.int/rec/T-REC-G.8262)
4. ITU-T G.8264, Distribution of timing information through packet networks (www.itu.int/rec/T-REC-G.8264)

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