Guide

CPE Best Practices and Selection Guide: Cisco ISR Positioning

For All Verizon Wireless 4G Services

Revision 4.1

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Introduction

There are many options for connecting enterprise, small/medium business and machine-to-machine sites. Coupled with an increasing number of remote deployment types, selecting an appropriate network device becomes more complex. Use of LTE 4G provides organizations with a powerful new primary and backup WAN connectivity option.

The purpose of this document is to offer best practices for the use of 4G cellular wireless as last mile remote site connection, to summarize and compare the options for enterprise connection, and to provide criteria and a rationale for use in selecting the appropriate device for the connection. This document is organized as follows:

- ISR Selection Summary
- Real-world examples with ISRs
- CPE Synopsis
- LTE for Enterprise/SMB/M2M Considerations
- LTE-Specific Characteristics for Routers
- LTE Connection Use Cases
- Enterprise CPE by General Use Case
- Frequently Asked Questions

There are 3 tables with these sections, each for a different purpose:

- In the CPE Synopsis section, the first table represents a summary of characteristics in support of 3 general use cases, including if the fixed or modular Cisco ISR models support the characteristic.
- In the LTE Connection Use Cases section, the second table provides an expanded list of use cases, along with key factors and business impact/benefit. Compared to the first table, this provides a more nuanced view of LTE use cases with a business perspective.
- In the Enterprise CPE by General Use Case section, the third table provides a more detailed list of functional, availability and performance characteristics, with Cisco CPE examples supporting LTE. Compared to the previous tables, this provides a more technically complete listing of networking characteristics.

ISR Selection Summary

The Cisco ISR is a family of Integrated Service Routers, meant for extending an organizations I/T infrastructure and applications to remote sites, in order to provide services to end-users seamlessly (similarly to end-users at the main locations). ISRs achieve this by providing traditional network functions (IP routing, non-IP routing, IP multicast, manageability, VPN, integrated/modular TDM/ATM/Optical/DSL/4G interfaces, integrated Ethernet switching) with enhanced functions (WAN acceleration, automation/self-recovery, IPS, content filtering, enhanced VPN, advanced 4G routing, hardware-accelerated encryption, and on-board virtualized services (VMs running on integrated servers).

Comparison of the ISR models are available at:

www.cisco.com/c/en/us/products/routers/4000-series-integrated-services-routers-isr/series-comparison.html

www.cisco.com/c/dam/en/us/products/collateral/routers/4000-series-integrated-services-routers-isr/enterprise-routing-portfolio-poster.pdf

3rd party evaluation of ISR performance is available at the links below. Although every model was not tested, relative performance of all models may be deduced by comparing the stated performance recommendations in the ISR data sheets with the results reported here:
Overview: www.miercom.com/pdf/reports/20091028.pdf Detailed: www.miercom.com/pdf/reports/20091001.pdf

Below is a brief summary of the ISR models for Verizon LTE:

- ISRs with LTE are available as fixed (807, 809, 819, 829, 899, 1111) and modular (1101, 4221, 4321, 4331, 4351, 4431, 4451, 1120, 1240) models. Fixed models have factory installed interfaces; modular models have available a variety of interfaces, accelerators and servers that can be embedded.
- All ISR models above provide integrated LTE support with Verizon Wireless LTE Public service (Internet access), Private Network service, Dynamic Mobile Network Routing service, Private network Traffic Management (LTE QoS), and Split Data Routing (dual network access from 1 SIM (public & private).
- All models integrate firewall, intrusion detection, content filtering, WAN acceleration, QoS, and robust IP routing.
- All models offer robust management and administration, including 4G MIBs, automation/self-healing, and monitoring/configuration via SNMP, SMS, dial-up, Telnet, SSH, and open APIs.
- Modular models allow integrated interfaces that make installation, configuration, operation and management easier (e.g. built-in LTE, built-in T1/T3 CSU-DSU). No additional external devices and associated cables, management complication, or availability issues.
- Modular models integrate additional WAN and LAN interfaces, voice interfaces, voice/video processing/ gateway/“bridging”, and additional virtualized services via on-board servers.
- 800 series fixed port ISRs offer lower costs, size and power usage, with many advantages of modular ISRs.
- The hardened model of the IR807, 819H, IR809, IR829, CGR1240 and CGR2010 provide cost effective enterprise and M2M LTE solutions to withstand conditions with significant vibration, heat, cold and humidity
- Routers that do not have integrated/embedded LTE interfaces: These can be replaced with current ISR models or with an 819 installed alongside the existing ISR to provide router redundancy, WAN backup, additional bandwidth, and out-of-band management.

Real-World Examples with ISRs

Highlighting real-world uses for network and device features can bring to life their value. While the remainder of this document lists characteristics and features, this section focuses on real-world needs that are met via programmability and function of ISR IOS software. Some examples will use IOS command line configuration, while others will use small files written in tcl and loaded to flash. The engine that drives these "apps" is IOS EEM (embedded event manager, www.cisco.com/go/eem). All the apps below are publicly available as-is (self-supported).

ISR LTE instant site survey via text message

This ISR app provides a way to receive radio signal measurements quickly, via an SMS text message, thus allowing immediate feedback and the ability to find the optimum spots to place antennas. There is no need for Web or command line access to the ISR. A smart phone is all that is needed. There are detailed test and short test options.

The app has been combined with other SMS-related functions into a single app, detailed in the Guide for ISR LTE Out-of-Band Management via SMS - Site Survey, 4G Usage, Diagnostics, and Configuration, available here:
www.cisco.com/c/dam/en/us/td/docs/routers/access/interfaces/software/deployment/guide/guide_isr_lte_sms.pdf
The tcl script and documentation can be downloaded from:
https://supportforums.cisco.com/t5/network-infrastructure-documents/command-over-sms/ta-p/3340391

Retrieving ISR LTE status, radio signal and ping results via text message

This app allows for using text messaging as a method to retrieve ISR LTE interface status, radio signal strength/quality, GPS coordinates (geographical location), and ping results. This is done by sending a text message to the phone number (e.g. MDN or MS-ISDN) associated with the 4G SIM in the ISR. The script is easily modified.

The app has been combined with other SMS-related functions into a single app, detailed in the Guide for ISR LTE Out-of-Band Management via SMS - Site Survey, 4G Usage, Diagnostics, and Configuration, available here:
www.cisco.com/c/dam/en/us/td/docs/routers/access/interfaces/software/deployment/guide/guide_isr_lte_sms.pdf
The tcl script and documentation can be downloaded from:
https://supportforums.cisco.com/t5/network-infrastructure-documents/command-over-sms/ta-p/3340391

Collecting GPS coordinates and radio statistics from an ISR

This app allows for automatic per-minute logging of GPS coordinates, radio signal strength/quality, and time stamp to a text file on the ISR's flash. This simple example could be expanded to send the results every hour to an application via FTP, email, etc. with the results from multiple locations aggregated and reported.

The app is detailed in the LTE GPS Guide for ISR and CGR, available here:
http://www.cisco.com/en/US/docs/routers/access/interfaces/software/deployment/guide/guide_120913.pdf
The configuration is also included in the same LTE GPS guide.

Synchronizing the ISR clock using GPS

This app provides a way to automatically set an ISR's system clock once per day by synchronizing with a GPS time reference (stratum 1), and for that ISR to be an NTP time server for other devices (e.g. for a closed network without access to a public or private time source). This sample could be expanded to send the file every hour via FTP or email.

The app is detailed in the LTE GPS Guide for ISR and CGR, available here:
http://www.cisco.com/en/US/docs/routers/access/interfaces/software/deployment/guide/guide_120913.pdf The tcl script can be downloaded from https://supportforums.cisco.com/document/12013976/gpstimezip

Viewing the location of an ISR from a Web browser

This app displays the location of an ISR on a map from a web browser (and thus the vehicle, kiosk, etc. the ISR is in). Location is updated at the top of each hour. The sample highlights other possibilities, such as displaying the path traveled on a map by combining the app with the per-minute location logging app above.

The app is described in the LTE GPS Guide for ISR and CGR, available here:
http://www.cisco.com/en/US/docs/routers/access/interfaces/software/deployment/guide/guide_120913.pdf
The tcl script can be downloaded from https://supportforums.cisco.com/document/12018071/findmyrouterzip

ISR Geo-Fencing

This app uses GPS to log, and optionally alert (text) and/or disable LTE when an ISR is operating out of an allowed geographic area. The app has adjustments for the range of the allowed area and actions taken once out of range.

The app is described in the LTE GPS Guide for ISR and CGR, below. The tcl script and documentation link follows.
http://www.cisco.com/en/US/docs/routers/access/interfaces/software/deployment/guide/guide_120913.pdf
https://supportforums.cisco.com/document/12150821/geo-fence

ISR Integration with Location Tracking Systems

This app uses ISR GPS function and its ability to stream NMEA formatted data to cloud-based and private location tracking systems. These systems are in use today, provided by system integrators for a variety of uses, such as police vehicles. The app has variables for the destination server IP address and port number for streaming the NMEA data.

The app is described in the LTE GPS Guide for ISR and CGR, available here:
http://www.cisco.com/en/US/docs/routers/access/interfaces/software/deployment/guide/guide_120913.pdf
The tcl script can be downloaded at https://supportforums.cisco.com/document/12239371/gps-nmea-streaming-over-udp

Monitoring monthly ISR LTE rate plan usage

LTE subscriptions may have a limited amount of traffic sent or received as part of the rate plan. This app monitors LTE traffic during a billing month, and logs a message if a defined percentage of the allowed bytes is reached. At the end of the monthly billing cycle, the app clears the LTE counters and begin counting anew. Variables included for tuning.

The app is summarized in the guide below. The tcl script and documentation are available at the subsequent link:
www.cisco.com/c/dam/en/us/td/docs/routers/access/interfaces/software/deployment/guide/lte_access_011414.pdf
https://supportforums.cisco.com/document/12098671/monitor-byte-count-over-4g-cellular-interfaces

ISR secure remote provisioning via SMS text

This app provides a method to complete an ISR's configuration via text message. If an ISR is shipped but used by an unauthorized party, it would not have access to the organization's private network. The app includes a shared secret sent with IOS configuration command(s). It can be enhanced to only accept messages from specific numbers, etc.

The app has been combined with other SMS-related functions into a single app, detailed in the Guide for ISR LTE Out-of-Band Management via SMS - Site Survey, 4G Usage, Diagnostics, and Configuration, available here:
www.cisco.com/c/dam/en/us/td/docs/routers/access/interfaces/software/deployment/guide/guide_isr_lte_sms.pdf
The tcl script and documentation can be downloaded from:
https://supportforums.cisco.com/document/12316801/commands-over-sms

ISR secure remote provisioning via SIM lock

This is a method using the integrated ISR web server to unlock the SIM. If the ISR is shipped but used by an unauthorized party, the ISR could not access the organization's private network and the SIM itself could not be used in another device for any LTE access. This method can be used to issue any display or configuration command.

The app is detailed in the LTE SIM Security Guide for ISR and CGR, available here:
http://www.cisco.com/en/US/docs/routers/access/interfaces/software/deployment/guide/LTE_SIM_Lock.pdf The method is also detailed in the same LTE SIM lock guide.

ISR interface status change alert via SMS text

The "Interface Status Change alert via SMS" app provides tracking of the status for any ISR interface; if the status changes, the ISR will send a text message with router name, time stamp, the interface name/address, and the state change. The sample provides a way to easily configure the phone number to text and which interface to monitor.

The app is summarized above in this guide, available here:
www.cisco.com/c/dam/en/us/td/docs/routers/access/interfaces/software/deployment/guide/lte_access_011414.pdf
The tcl script and documentation can be downloaded from
https://supportforums.cisco.com/document/12125666/sms-notification-when-interface-changes-updown-state

ISR Traps via SMS

This ISR app provides the ability to notify a network management system (NMS) of loss of WAN connectivity for a Cisco ISR (8x9, ISR 4K, CGR, 19xx, 29xx, 39xx series) using 4G LTE (cellular wireless) networks. It can do so in cases where LTE is the only WAN connection to the site. The applet has two parts: a text message sender running on the remote ISR, and an SMS-to-SNMP trap gateway running on an ISR reachable by the NMS.

The app is summarized above in this guide, available here:
www.cisco.com/c/dam/en/us/td/docs/routers/access/interfaces/software/deployment/guide/lte_access_011414.pdf
The tcl script and documentation can be downloaded from
https://supportforums.cisco.com/document/12758456/snmp-trap-over-sms

ISR Auto Restoral – From 3G to 4G

This app provides the ability for a Cisco ISR, IR or CGR router to automatically return its cellular service to 4G LTE if it has fallen to 3G or 2G (if LTE service is available). Without the applet, the router may remain on 3G even if LTE service is available. The behavior to remain in 3G mode is due to current LTE standards as implemented in LTE modems and networks. Without this app, if there is no "quiet" period of 5-7 consecutive seconds (no traffic sent or received) the LTE modem will not return to 4G operation.

The app is summarized above in this guide, available here:
www.cisco.com/c/dam/en/us/td/docs/routers/access/interfaces/software/deployment/guide/lte_access_011414.pdf
The app and documentation are available here:
https://supportforums.cisco.com/document/12620516/restore-lte-service

CPE Synopsis

In addition to handheld mobile devices, LTE is being leveraged by organizations for a variety of use cases, including

- simple machines (meter, sensor, vehicle diagnostics, M2M, IoT)
- complex machines (kiosk, ATM, vehicle diagnostics + multi-user internet access, construction vehicle, M2M)
- temporary sites (sports/fair/conference WiFi access, temporary work site)
- small/medium business/retail site and enterprise remote location or retail site

The equipment most applicable to the use can be based on a combination of function, deployment/management ease, performance, and physical/environment needs. This table can be used for comparison purposes with various CPE.

Characteristic (by use case)	Example(s)	Fixed ISR/IR	Modular ISR/IR
Enterprise Remote Location			
Modular interfaces/ports	T1, T3, voice trunks, PoE Ethernet, serial, console (mgmt)		Y
Multiple/Simult. LTE interfaces	2/3/4 active LTE connections, same or different networks		Y
QoS over LTE	Condition traffic onto an LTE best-effort bearer (available today)	Y	Y
Integrated LTE hardware, diagnostics, management	Embedded h/w + full diagnostics and control, for example, can provide SINR/RSRP/RSRP, can sync GPS time to router time	Y	Y
Automation and self-recovery	Alert, retry, reroute traffic, self-configure, etc. based on an event, message, date/time, environmental condition.	Y	Y
Robust management	Support SNMP (including 4G MIB), access via console, Telnet, HTTP. Logging, DM logging, traps, email, SMS mgmt interfaces	Y	Y
IPv6 and non-IP routing support	IPv6 routing, SNA, IPX, Bisync/BSTUN (banking). Support for ISR IPv6 over LTE targeted for 2014. Use 6to4 over prem-based VPN.	Y	Y
IP routing, enterprise grade (with tunable timers to comply with 4G network requirements)	BGP, EIGRP, OSPF, RIP, policy-based routing, tunable timers for fast failover, VRRP, HSRP, NeMo, PMIPv6, L2TP, MPLS, etc. Ability to tune timers to not exceed 4G network overhead limits	Y	Y
Advanced VPN & Security Options	QoS within VPN, Support multi-VRF within VPN, GETVPN (used for Verizon DMNR and Managed ATM services), content filtering	Y	Y
DMNR	Mobile IP NeMo support, for Verizon LTE service allowing LTE to be used as a last mile access into enterprise networks	Y	Y
Maintenance options	Warranty, options for up to 7x24x365 TAC & field replacement	Y	Y
Robust Ethernet switch ports	10/100/1000, PoE, OAM, dual 802.1Q tagging, 802.1P, detailed statistics, settable MTU, methods to reduce fragmentation.	Y* sub-set	Y
Small/Medium Business Site			
Priced for small deployments	Cost to an organization at a level permitting use in small locations	Y	
Security features	IPS, firewall included, options for cloud-based security services	Y	Y
VPN Support	Hub/Spoke, mesh VPN definition. Simple remote site config, available GUI interface for config and monitoring	Y	Y
Integrated Ethernet switch ports	At least 4 switched LAN ports with auto failover/fallback to LTE	Y	Y
WiFi for business & Guest access	Integrated WiFi may be feasible for a very small location, WiFi APs are recommended for > 1000 sf, multiple rooms/floors, etc.		Y
Temporary Sites			
External antennas	Support external LTE antennas with available SKUs for indoor and outdoor, and extension cables, fully supported via TAC	Y	Y
GPS Support	Active GPS support, via separate or combined antenna. Ability to log coordinate or alert if coordinates change (geo-fencing)	Y	Y
Machines (M2M)			
Hardened (IEC/NEMA specs)	Operates in needed temperature, humidity, vibration ranges	Y	
DC power option	Operates with 12/24 volt power source	Y	Y
Small size	Examples: 7” x 7” x 2”, 5” x 6” x 1”, etc.	Y	

LTE for Enterprise/M2M/SMB – Synopsis

Cellular Wireless is a complimentary last mile access to wireline. Wireless can be used as backup for wireline and vice versa. LTE can also be used as primary access. A brief comparison table below may assist in determining which last mile access to leverage for a particular use case or site.

Characteristic	LTE	Broadband Wireline	Private Wireline
Technology	Cellular Wireless (assumes category 4)	Cable, PON, DSL, Metro-E etc.	T1, T3, OCX, Metro-E, etc.
Monthly Cost	Varies by subscription plan (a number of bytes/month included). Can be Lowest cost depending on rate plan and bytes used/month	Varies by speed and geography. 2X-4X cost of LTE, but there is generally no monthly byte count cost consideration.	Varies by speed, geography, and distance between locations. Highest cost.
Usage Cost	Varies by subscription plan. Charge per GB over plan, but can pool subscriptions.	Usage caps are not common and if in place may be higher than 100-300 GB/month.	None.
Where it is Available	Most locations in the U.S. and most densely populated locations worldwide.	Locations in urban areas and suburbs, varies by provider.	Locations in urban areas and suburbs, varies by provider.
Bandwidth	Varies by RF conditions and service provider. Asymmetric. 5-60Mbps down, 1-20Mbps up.	Varies by technology and provider. Asymmetric or symmetric, 768Kbps-1Gbps down, 384Kbps-1Gbps up.	Varies by technology and provider. Generally Symmetric, 56Kbps-1Gbps down, 56Kbps-1Gbps up.
Throughput	Varies by RF conditions and network congestion, as “last mile” is shared.	Varies by network congestion, as some Internet paths are shared.	Consistent.
Availability (Uptime)	Varies by RF conditions, generally > 99.5%.	Varies by service, generally > 99.9%.	Varies by service, generally > 99.99%.
Provisioning/Installation	Varies by service, usually a few days. Easy to move an LTE router to new locations without affecting service.	Varies by service, usually a few weeks. Moving existing lines to a new location requires re-provisioning.	Varies by service, usually a few months. Moving existing lines to a new location requires re-provisioning.
Usage Restrictions	Subscription plans may restrict non-user traffic frequency, affecting routing protocols, probes, etc.	Generally none.	Generally none.
Mobility	A site/router can be moved to another location. It can also operate while in motion (trucks, buses, cars, trains).	None.	None.
Security	Varies by service, can use public service with VPN, or can use a private service (generally as secure as private wireline).	Usually a public service requiring firewall and VPN.	Private connection does not “touch” public networks.
Side-Band, Out-of-Band management or reach	Even if data connection down, SMS may be usable for out-of-band management	None inherent to the connection.	None. Inherent to the connection.

LTE for Enterprise/M2M/SMB - Considerations

4G cellular wireless has historically been leveraged for consumer services, providing hand-held devices with email and web access. Mobile devices have revolutionized the way people communicate, expanding from just voice to include instant messaging, GPS, SMS, email, web browsing, networked applications, and video communications. Enterprises have leveraged the technology, initially for employee hand-held mobile devices.

An increasing number of organizations leverage 4G as a last mile access option for multi-device remote sites. The results have been mixed, due to cellular wireless having different characteristics from wireline. With an understanding of the characteristics and proper planning, successful results can be achieved with 4G LTE WAN access.

What follows is a summary of the major differing characteristics of landline and wireless access, along with guidelines for how to leverage or mitigate these characteristics for remote site 4G use.

Connection variability: Given the nature of wireless communications, 4G LTE does not offer the same consistency of bandwidth, error rate and latency as wireline. This is due to factors such as location (distance from radio towers, multipath from radio signal reflections, radio interference from other sources, etc.), weather, and bandwidth usage (4G is "last mile shared access". These factors can vary over time.

In order to deliver highly reliable and consistent performance, an understanding of the RF conditions at each installation is needed. Additionally, appropriate antennas, cables and placement can be done for each installation. Business-grade 4G CPE can provide radio signal statistics (RSSI, RSRP, RSRQ, SINR) as well as multiple supported options for antennas and extension cables. The performance and reliability difference between a site with and without optimal antenna type and placement is significant. Cisco ISRs have multiple antenna types (indoor, outdoor, omnidirectional, directional) and cable lengths as standard orderable SKUs. ISRs provide detailed radio reception statistics, including a historical summary. A no-charge ISR app is available for site survey via text message.

The variability of available bandwidth needs to be considered regarding the effect on application performance and QoS policy. To summarize wireless connection variability, wireless offers many advantages for last mile access, but its bandwidth consistency is not equal to private wireline access methods.

Connection Permanence: Wireline connections tend to be permanent, i.e. permanently "up/up" (physical interface/ line protocol). Also, the connection across the last mile tends to be dedicated, such as fiber or copper wires. 4G wireless does not have connection permanence at two levels. Both levels are described below, with considerations.

4G logical permanence is similar to dial-up, where a "call" is placed to bring up the cellular connection. For routers, this is based on "interesting" traffic or the absence of an IP route in the mobile router's routing table. Unlike most wireline connections, the ISR's state of a 4G cellular interface before network connection is up/up spoofing. To bring up the logical connection requires appropriate configuration, and entails a delay (approximately 20 seconds).

The method to bring up the configuration depends on the goals of the organization. An on-demand connection (in order to save line usage costs) may use the "interesting traffic" method. An always-on connection (little usage costs if cellular is not the primary path) may use the bring-up method based on a "missing IP route". Always-on is recommended to ensure the service is always available (alert if 4G connection becomes unavailable). *The key points are: 4G requires configuration based on design needs in order to provide logical connection permanence, the LTE connection is not always active, and it may take 20 or more seconds to bring up the initial connection*.

The logical connection can be interrupted for various reasons. Based on the configuration, the connection should automatically be restored in approximately 20 seconds. Some reasons for a connection to be reset include:

- Scheduled maintenance within the Cellular network, for cell tower or the core components. There are backup components, however sometimes during the primary-backup takeover, the session may drop.
- If no traffic is sent to/from the router over cellular, the logical connection will be taken down by the network. The time varies depending on network provider and service used. For example, a 2 hour timer is common.
- The router modem's Radio Access Technology drops from LTE to HRPD or 1xRTT (see below)
- The router modem's Radio Access Technology returns to LTE from eHRPD, HRPD or 1xRTT (see below)

4G physical permanence refers to the radio link and connection between the router cellular interface and the cell tower (e.g. eNodeB). While the logical connection tends to be longer lived, the RF connection (radio bearers) can be torn down to reuse radio resources for other wireless devices. The key concept is that the 4G physical connection is a shared medium. The balance between efficient use of the medium and the cost of signaling has an impact on mobile router configuration and tuning. The factors below provide understanding of how 4G is different than wireline (what the impact is) and how to configure to get the most from the cellular wireless connection.

- RF usage: Most devices on a 4G network are handheld devices or small machines that do not require always-on connection. After a few seconds, the devices become "idle" on the network. A router's configuration may block the connection from going to idle mode, thus rarely releasing radio resources. Cellular radio resources are costly and meant to support many devices. Because of this, providers may have guidelines for devices sending non-user traffic such as frequent periodic pings, probes and routing protocol updates. *The router should be configured to balance the need for real-time control traffic with appropriate radio use. This can be determined through discussion with the cellular wireless provider*.
- Latency: 3G wireless networks have 1-way latency of 100-200ms and 4G network have 1-way latency of 30-60ms. In regards to application/device end-to-end latency requirements, it's important to consider this latency along with those of other parts of the network, and what the actual packet path is. This can be done using performance tools and the "traceroute" command. *Application or device time-out values may be adjustable to accommodate the addition of 4G network latency to the rest of the network path*.
- Packet Loss: Cellular wireless uses radio frequency modulation across distances, with varying weather, physical obstacles, electrical interference and user density. 4G protocols have buffering and retransmission at layer 2 to protect against loss. But a small amount of packet loss is to be expected. Depending on the Layer 4-7 protocols supporting an application, retransmission is done for lost IP packets. *Application, device and management system adjustment may be done so that a single lost packet or a few lost packets in a short (few second) time frame is not seen as serious condition (e.g. raising an NMS alarm).*
- RAT failover and fallback: 3G/4G protocols define behavior between the wireless modem and cell tower to dynamically change the RAT (Radio Access Technology, e.g. 1xRTT, HRPD, eHRPD, LTE). Depending on radio conditions and cell tower capabilities, a cellular device may failover from LTE to another RAT. If the conditions change again, a cellular device may "fall back" from 2G or 3G operation to LTE. This is impactful for 3 reasons.

- Operating in 2G or 3G mode may offer significantly lower throughput to the mobile router. *Using ISR programmability (EEM), the RAT can be determined, an alert sent so that appropriate problem determination, and/or actions to fall back to LTE can be automatically initiated by the ISR itself.*
- To fall back (return) to 4G operation from all 2G/3G modes requires the cellular modem to be in "idle mode". Idle mode is a radio state where radio bearers assigned to a wireless device have been temporarily released; idle mode can only be achieved if there is no traffic to/from the device for a certain time. Depending on the RAT and service, this time is 5-10 seconds. If the router is receiving or sending packets in a pattern that precludes a "silent" time period, service cannot return to LTE. *Using ISR programmability (EEM), this condition can be sensed and alerting and/or automatic recovery (perhaps at a specified time of day) can be accomplished. The ISR can also be configured to lock the RAT to LTE only (check radio signal quality and other consideration before setting).*
- Certain failovers (LTE-1xRTT, LTE-HRPD) and all fall backs will reset the logical connection, causing the cellular interface to reset, and pausing data transmission/reception for 20 or more seconds. This is part of the 3G/4G (3GPP) specification. *ISR configuration can reduce the automatic interface re-enablement time to less than 20 seconds.*

RAT failover/fall back is not a common event for stationary wireless devices if the installation includes a site survey yielding well placed appropriate antennas. Information regarding how to determine "good" radio signal, LTE antenna options, and available site-survey ISR applications are included in the ISR LTE antenna guide, mentioned in the "Real World Examples" section earlier in this document.

Connection Performance: In addition to LTE being a shared wireless media, performance is bounded by the radio access technology category. Cisco ISRs and IRs have LTE modems with Category 4 specification (maximum theoretical performance of 150mbps down, 50mbps up). On the horizon are Category 6 (300mbps down, 50mbps), Category 1 (10mbps down, 5mbps up), and Category 0 (1mbps down, 1mbps up). The rationale for Category 6 is as expected. Use of Category 0 and 1 may not be self-evident. For M2M (machine-to-machine) or IoT (Internet of Things) use cases, lower power lower performance wireless is important. This allows lower cost, lower power radios, which can operate in small devices with batteries for a number of years. Cisco ISRs and IRs today support alternate technologies for M2M/IoT, due to the following:

- ISRs usually support multiple devices connected behind it. Cat 0 is focused more on a single device
- ISRs usually support applications or devices with robust needs (interactive, aggregation, programmability, translation/gateway). Cat 0 is focused on short, periodic, simple transfers
- Uses cases for low speed wireless (sensors, low battery usage, simple function) often are supported by unlicensed bands with technology such as LoRa, allowing no monthly LTE charges for the many small devices/sensors. Another consideration is that the many small devices (often in hard-to-reach locations) do not require replacement if for example the LTE technology changes or the LTE carrier changes. The use case aggregates the many small low speed devices through an ISR or IR, which can provide data translation, buffering, acceleration, compression, high availability, and QoS (it is difficult to provision LTE QoS service for every sensor).

Public vs. Private Networks: 4G access can provide public or private network access, similar to landlines.

- Public access supports connection to the Internet, for communication with public services and public cloud infrastructure. Public access can support private network connection via overlay VPNs (tunnels).
- Private access supports connection to an organization's private network, using that organization's IP addressing and security architecture. Private access can support connection to the Internet via a gateway or firewall within the organization's own network.
- Public and private access services have different security, management and cost characteristics. Contact a Verizon representative to determine the option that best fits the need.

Network design: 4G designs use tunnels, the type(s) of which are dependent on the cellular wireless technology and the service chosen. For remote site deployments with multiple users per site, there are 3 Verizon options.

- Verizon Private Network service (Verizon PN) provides for the remote router's 4G WAN address being part of the enterprise's IP address space. This service is commonly used with single-user mobile devices, and routers using overlay customer-prem-based VPNs.
- Verizon Private Network service with Dynamic Mobile Network Routing (DMNR). This service is commonly used with routers (no overlay customer-prem-based VPN needed) and single-user mobile devices.
- Verizon public network service (Internet). This service is commonly used with overlay prem-based VPNs and firewall/IPS/anti-virus software (given the connection to the Internet).

To understand the differences between Verizon PN and Verizon PN with DMNR, a brief review of private data networking over wireless follows. For a mobile device to securely connect to an enterprise network, that device must be seen as part of the enterprise network addressing space. This can be done for devices on the public Internet using a tunneling protocol (IPsec, SSL, etc.), or for the case where the device is 4G connected via Verizon Private Network service, which can scale greater at lower cost, and can be offered as a network-based service.

Verizon PN is a service that offers last mile access to a private network via 4G LTE or 3G EVDO connections. A mobile device (smartphone, etc.) or router WAN interface is connected to an organization's private network via Verizon Wireless mobile gateway services and can reach/be reached within the enterprise network as if connected via wireline. For a mobile router, only the WAN interface is connected to the enterprise network, not the remote subnet(s) behind the mobile router. To connect those remote devices, the mobile router must use either Network Address Translation (not recommended for enterprise access), or overlay tunnels must be provisioned between each mobile router and an enterprise customer-prem aggregation device (cost and scale issue). Common overlay tunnels methods include GRE, IPsec, GRE, L2TP, PPTP, and SSL.

DMNR is an optional service provided by Verizon for the Verizon PN service. DMNR leverages the NeMo protocol to provide 4G-as-last-mile connection as described above. NeMo stands for Network Mobility (RFC 5177), and is an enhancement to Mobile IP. NeMo technology enables a router and its subnets to be mobile and/or connect using LTE as last mile WAN for IP connectivity, transparent to the IP hosts connecting to the network through the mobile router. This enables the devices on a subnet behind a mobile router to transparently connect to the enterprise network through 4G.

DMNR enables 4G private network connection, whether the site is stationary (LTE-connected branch) or mobile (a bus or train with passengers staying connected).

The devices on the mobile network are not aware of IP mobility. NEMO running on the mobile router 'hides" the IP roaming from its attached devices so that the devices appear to be directly attached to the enterprise network. NeMo technology adds the network(s) behind the mobile router to what's registered with that organization's Verizon Private Network. The Verizon Private Network then advertises reachability into the organization's private network; routing of traffic bi-directionally is supported. The subnets behind a mobile router, from the enterprise network perspective are no different than subnets connected via private leased line.

Verizon PN is often used for user mobile handsets (so that the user's mobile device data connections never traverse the public Internet). Verizon PN with DMNR should always be used to support a remote site router connecting to the enterprise network. DMNR ensures that the network(s) behind the remote router are fully supported without additional overlay tunneling provisioned, so that all user data never traverses the Internet. These types of connections are as secure as leased line access to Private IP (with LTE, user plane radio signals are AES 128 bit encrypted).

When Verizon PN is used for a router with a network behind it (a typical remote site), an additional overlay tunnel design is required, such as GRE or IPsec VPN (hub/spoke, EZVPN, DMVPN). If an organization uses Verizon PN with one of the prem-based VPN solutions above, the organization self-supports configuration and troubleshooting, and should ensure that the tunnel keep-alive or IP routing protocol frequency complies with Verizon M2M Network Usage Guidelines.

If end-to-end encryption is not required, this additional requirement significantly affects the scalability and operational/acquisition costs of the solution. In addition, Verizon 4G networks require that all packets leaving the router towards the 4G network have the router's cellular interface's IP address as the source address. Non-conforming packets are considered IP packet violations and cause the cellular network to disconnect the router's cellular interface from the network. This requires additional planning, to ensure that every packet meets this criteria. Some installations have had connectivity issues due to this (ill-defined access-lists for VPN traffic, traffic sourced by the router for SNMP, NTP etc.).

For enterprise remote site connection, DMNR provides significant advantages. DMNR does not require an additional manually provisioned overlay tunnels nor customer prem VPN equipment, and inherently avoids IP packet violation issues. This significantly increases scalability and reliability, while reducing potential costs and outages.

End-to-End Encryption: When an enterprise requires end-to-end (CPE-to-CPE) encryption, Verizon PN + DMNR offers a scalability and performance advantage over Verizon PN alone. Traditional IPsec VPN designs (IPsec tunnel mode, EZVPN, DMVPN) require distinct tunnels between each remote site and at least one other site (main site or other remotes). This requires a minimum of 3 tunnels (one bi-directional for ISAKMP, two unidirectional to allow 2-way user traffic). For DMVPN, each additional site a remote location communicates with directly also requires at least 3 tunnels. Tunnel overhead (keep-alives, state maintenance, etc.) requires additional processing overhead, which is more acute on the head ends at main locations. This traditional tunnel-based design is required when using Verizon PN alone or public LTE service, as there is no enterprise routing for the networks behind the remote routers. Thus traffic must be tunneled.

GETVPN: One key difference between Verizon PN + DMNR and Verizon PN alone is that DMNR natively provides for advertising and routing of networks behind the remote router. When end-to-end encryption is needed, Verizon PN + DMNR allows for the use of GETVPN (Cisco Group Encrypted Transport VPN). GETVPN provides tunnel-less end-to-

end encryption for network traffic without affecting an organization's IP topology. GETVPN uses the organization network's ability to route and replicate packets between sites within an enterprise.

GETVPN allows greater scale and simplicity by preserving the original source and destination IP address information in the header of the encrypted packet for optimal routing. It is well suited for encrypting on MPLS private networks and for encrypting multicast traffic. GETVPN allows for seamless integration with an existing private network while enabling cookie-cutter remote site VPN configuration (all identical) compared to traditional methods. A prerequisite for GETVPN is routing to/from any subnet behind mobile routers, and is met by DMNR.

Integration of 4G into private network deployments: Simply supporting 4G as an IP interface may not be sufficient to enable a router's use in a private network. The LTE interface should support similar private network features as a wireline interface (as is feasible) and not inhibit users' access to business functions. This entails both the actual features, and the interaction between features. For example, a router may be able to support IP routing protocols, and support VPN, but be unable to support routing protocols across the VPN (which may be required for appropriate routing within the private network). An additional 5 integration examples are below.

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- Integration into an existing Virtual Private Network: The need for CPE-based VPN network overlay may be preferred, or the option of supporting a network-based highly scalable, easily deployed option may be best. The CPE which supports both methods and multiple options for each will provide flexibility and growth. The Cisco ISR supports NeMo, PMIPv6 (the IPv6 equivalent), IPsec, IPsec/GRE, DMVPN (with VRF support), Note that not every VPN type is supported by every network service. Contact Verizon for details.
- Integration with an existing private network: Support for multiple WAN connections and a variety of IP and non-IP routing protocols allows for supporting various existing private network designs. The Cisco ISR supports multiple interfaces simultaneously with load sharing, including multiple LTE interfaces/radios. Note that not every ISR feature is supported by every network service. For example, multiple LTE radios can be used simultaneously with DMNR, with one in primary and one in backup mode. To use multiple LTE radios simultaneously with DMNR, one interface would connect to DMNR and one or more interfaces would connect to Verizon public network service for Internet access or customer-prem-based VPN.
- Integration with a wide variety of routing protocols: The ISR also supports RIP, OSPF, BGP, IS-IS, PfR, LISP, policy-based routing, and static routes, along with HSRP and VRRP for high availability.
- Integration with other routing functions: The LTE interface should be configurable and manageable as other WAN interfaces. This includes robust diagnostics (e.g. LTE DM logging), 4G SNMP MIBs, support for IP routing protocols and VPN technologies across the LTE interface, control of radio technology selection (4G only, 2G/3G/4G with failover/fallback). The ISR supports these functions.
- Quality of Service (QoS). The LTE interface should be able to mark, classify, prioritize, and rate limit user traffic based on its importance to the organization.
- GPS location and time sync integration, and automation. This includes displaying, recording and sending of location information, geo-fencing (enforcement to only operate within a certain geographical area), setting the

router clocks via the GPS time source, time or event-based LTE connect/disconnect. The Cisco ISR can support these functions.

- Support SIM security (ability to lock, unlock, change the PIN of the SIM to ensure it cannot be used in another device and allow unauthorized access to the network. This Cisco ISR can support this function.

Deployment guides for most of these functions on the Verizon LTE network can be found at
www.cisco.com/en/US/products/ps5949/products_installation_and_configuration_guides_list.html

LTE-Specific Characteristics for Routers:

The following functions are specific to the 4G interface and apply to enterprise and some SMB and M2M deployments.

Availability:

- LTE port interfaces with router to allow deep level of control (tunable timers, automation, rerouting, and SNMP alerts based on specific radio conditions)
- Available SNMP MIBs or other standardized method to monitor and alert on specific radio conditions, if radio moves from LTE, EVDO, 1xRTT
- Seamless integration of LTE interface into router
    - control of interface and connection (from router to Verizon PN)
    - same configuration, control and features available for other WAN interfaces
- Event logging, diagnostics, statistics gathering, history/reporting (including remote low-level modem logging ability over the IP network)
    - For LTE module, interface, radio and SIM
- Robust self-healing and automation to restore service regardless of one or multiple outages or issues (example is via EEM scripting, IP SLA, etc.)

Performance:

- Significantly greater throughput compared to consumer USB modems
    - MIMO technology, greater antenna choices, detailed radio statistics for improved antenna placement
- Support for LTE, eHRPD/EVDO revA and 1xRTT in same module/radio
    - With switching between networks in case of coverage gaps
    - Option to lock the radio access technology (e.g. only 4G, or only 3G operation)
- Tunable timers:
    - Fast/programmable enhanced idle timer: “wake up” of radio interface (LTE and EVDO and 1xRTT) for unsolicited/downstream traffic
    - Timers to fine tune backup/recovery bring up/down of the LTE interface for fast enterprise traffic rerouting, and for efficient LTE network operation
    - Deep level of control (tunable timers, automation, rerouting, and alerting based on specific radio conditions) for optimizing throughput, efficiency and reception.
- Reception quality
    - Connections for 2 antennas. Testing shows that the difference between setting the same pair of antennas similarly located 2” and > 17” apart (LTE wavelength) increased throughput by up to 50%.
    - Available low loss shielded cables (10 to 75 feet) for both antennas. Allows separation and placement for improved diversity and mitigating multipath effects, without affecting router location
    - At least one 10’ low loss shielded cable provided at no cost
    - Supported antenna options such as “rubber duck”, indoor/outdoor mast, and outdoor “hockey puck”, offering greater flexibility in gaining the optimum signal strength and reducing multipath.

- Quality of Service (QoS):
    - If in the future, dedicated LTE bearers for enterprise traffic become available, the router should map traffic classes to LTE bearers with traffic conditioned to not exceed the contracted rates.

LTE Connection Use Cases:

There are use cases for organizations looking to leverage LTE, each with its own business impact, and justification. Below is a table with a more granular view of use cases for CPE, with a summary of their characteristics from a business perspective. The purpose for defining these is to provide a way to consider the criteria described above for each.

Description	Application, # Users	Key Factors	Business Impact
Stationary Enterprise Remote Branch	Remote office with a robust suite of business's functions and network requirements. Few to very many users & applications.	Availability, performance, and enterprise features. May need to support multiple WAN types (T1, T3, ATM, optical, PoS, DWDM). LTE backup, auto failover/fallback to reduce costs	Can provide lower cost more flexible quickly deployed WAN option for primary or backup link.
Stationary Small/ Medium Business Remote Branch	Remote office with a suite of business functions. Few to many users & applications.	Availability, performance, and a subset of enterprise features. For LTE backup, auto failover & fallback. Cost and Ease of deployment and management.	Can provide lower cost more flexible quickly deployed WAN option for primary or backup link.
Temporary Branch or Venue	Remote office, business conference, entertainment event. Few to very many users.	Deployment/teardown speed, availability, and performance are critical. Enterprise feature set need varies by use case. For LTE backup, auto failover & fallback to reduce costs	Fast easy deployment with acceptable performance and features needed to avoid loss of business or enable temporary locations
Stationary Machine (Kiosk, ATM, meter, etc.)	A single or few application-specific machines/portals	Fixed and/or temporary location May need to support non-IP protocols e.g. SCADA or Bisync using serial interfaces.	Provide functions without on-site personnel, with lower costs and increased hours of operation.
Machine in Motion (vehicle diagnostics, heavy machinery control/analytics)	A single or few application-specific machines/portals providing services for vehicles and moving machinery.	Traveling/moving within a work area. Reliable connection in difficult environments. May need hardening or DC power.	Diagnostics and control of equipment regardless of location and track location, path and speed.
Mobile Office	An office "on wheels" with a suite of business functions. Few users, a trailer, bus, etc.	On the move or stationary. Allows untethered connection regardless of location.	Provide business functions reliably and consistently regardless of the location
Stationary Teleworker	Single user working remotely. Applications related to the user. May support just a laptop/tablet or also a printer, IP phone, etc.	Not generally mobile. e.g. work-at-home user. LTE for out-of-footprint broadband	Provide low cost, reliable and sufficiently performing secure access to apps for remote employees.

Enterprise CPE by General Use Case

There are various devices available for 4G deployment. The table below provides a mix of the specific features and availability/performance characteristics, mapped to examples of CPE that may be used. This is a different view from the two previous tables, meant to provide another perspective. Although classifying devices may not provide sufficient granularity for selection, it may assist with general criteria in order to make an appropriate selection per use case defined earlier. Towards that end, 3 basic product levels are considered, along with characteristics (relating back to the general and LTE characteristics mentioned earlier):

Class	Features	Availability	Performance	Product Example
Enterprise and M2M	Supports NEMO, PMIP, IPsec, GETVPN, DMVPN, EZVPN, GRE, BGP, EIGRP, OSPF, RIP, IPS, Firewall, Voice, Video, integrated 4G ports, multiple WAN interfaces & load sharing, App Optimization, per-flow-protocol-destination traffic reporting, Larger locations: modular slots to support various WAN, LAN, virtualized application services	SNMP, Syslog, auto-reroute via IPSLA, & routing protocols, supports multiple 4G interfaces, in-band and out-of-band device access, in-band and out-of-band modem/radio access and diagnostics. For M2M hardened	ASICs to offload specific tasks, non-blocking internal architecture, granular QoS to prioritize traffic, guarantee minimum throughput, condition traffic to minimize drops. High packet per second throughput with multiple services enabled. > 20mbps combined bi-directionally	ISR 4xxx or CGR with LTE NIM/CGM module, 8xx or 11xx with embedded LTE port
Small Medium Business	Supports multiple users, NAT, basic VPN and Firewall, support at least one WAN interface in addition to the 4G port, usually Ethernet	Easy to deploy and manage, reduced cost, Basic security and VPN functions at no charge.	Sufficient performance to support a small/med number of users or devices (1-20mbps combined bi-directionally	Meraki MX series security/WAN appliance with LTE USB modem
Machine to Machine	Support single device or multiple devices, either over Ethernet or serial connection.	May require hardening or .DC power.	As appropriate for a single user	IR8xx hardened or CGR with LTE module

CPE Frequently Asked Questions

Q) Can ISR G1 (1800, 2800, 3800) support embedded LTE interfaces?
A) No. The G1 models were announced as end-of-sale on November 1, 2010; hardware and software maintenance ended in 2014. The current ISR models (809, 819, 829, 1900, 2900, 3900, 4321, 4331, 4451) support embedded LTE interfaces.

Q) Can I still purchase new ISR G2 (1900, 2900, 3900) routers and LTE interfaces?
A) Most G2 models are end-of-sale starting December 9, 2017. The current ISR models (807, 809, 819, 829, 1101, 1111, 1120 1240, 4221, 4321, 4331, 4451) support embedded LTE/LTE-A interfaces with superior price/performance.

Q) Can ISR 1000 and 4000 series embedded LTE interfaces support external antennas, GPS, clock sync via GPS, remote monitoring and configuration via SMS, and detailed LTE radio statistics?
A) Yes. See the guides at www.cisco.com/c/en/us/support/interfaces-modules/high-speed-wan-interface-cards/products-installation-and-configuration-guides-list.html

Q) Does the ISR 4000 series support modules for embedded LTE and the same functions as ISR G2 with LTE?
A) Yes, the ISR 4221, 4321, 4331, 4351, 4431 and 4451 support one or more LTE NIMs (Network Interface Module).

Q) Are there hardened (for temperature, weather and vibration) models of the ISR G2 with embedded LTE?
A) Yes, the IR807, IR809, IR829, C819HG, CGR 1120 and1240

Q) Can multiple LTE interfaces be used on a single ISR?
A) Yes, on 829 and all modular ISRs/CGRs, as many as the number of NIM slots on the ISR.

Q) Can multiple ISRs with LTE be used in active/backup or in parallel?
A) Yes. IRs, ISRs and CGRs support HSRP, VRRP, and GLBP.

Q) Can Meraki support LTE interfaces?
A) Yes, on MX series via LTE USB modems.

Q) Where can I find information on Meraki LTE support?
A) https://docs.meraki.com/display/MX/3G+-+4G+failover

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