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VOICE OVER LONG TERM EVOLUTION SERVICE QUALITY MEASUREMENTS AND DIAGNOSTICS USING MACHINE LEARNING TECHNIQUES

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ABSTRACT

Techniques are described for a machine learning based Voice over Long Term Evolution (VoLTE) trouble-shooting/diagnostic approach which can look at various data sources in the mobile packet core and identify the key issues by observations and correlations across data fields using machine learning techniques. It helps mobile operators to quickly identify fault domains in VoLTE calls and take corrective actions to enhance customer Quality of Experience (QoE).

DETAILED DESCRIPTION

Leveraging the Internet Protocol (IP) and Quality of Service (QoS) capabilities of the Long Term Evolution (LTE) network, operators all over the world are deploying Voice over LTE (VoLTE) services. For most of these operators, realizing a stable, high-performing VoLTE network with the best end-user experience is proving to be a major challenge. A customer's complaint (e.g., "I place a VoLTE call, the other person picks up the phone, but I do not hear anything") may not allow the operator to diagnose that issue and identify the root cause. Operators also do not have the ability to proactively identify such issues in each of the cell-site locations and take corrective actions.

There are many point tools in the market for VoLTE service measurement. One can carry an expensive 100-pound box and insert it in one point of the network. That box, based on some packet sniffing on that link, can generate some diagnostics data which can be used for identifying some issues. However, the analysis data from these tools is often flawed and incorrect, as the analysis is on a partial set of data. These tools do not have visibility into all the elements and data sources impacting that VoLTE call, or the ability to establish correlations across those elements. In the absence of such a comprehensive view and correlation capability, operators have no means to measure VoLTE service performance, and for characterizing the end-user experience in a precise manner.

To address these issues, an approach is provided which may examine various data sources in the mobile packet core and identify the key issues by observations and correlations across data fields using machine learning techniques. The data sources of interest may include performance related to an air interface, IP Multimedia Subsystem (IMS) signaling, data plane, backend interfaces, cell conditions, Public Data Network (PDN) / bearer, cell to cell transport, and RTP media. Preliminary results based on small test data indicates that issues may be identified with a high success rate. Though the focus of this work is on an LTE network, the approaches described herein are equally valid for Wi-Fi® calling on a Wi-Fi access network. Identified are the key elements, data sources, measurement techniques, data pipelining approaches, correlation techniques, target behaviors, and associated output elements.

In this approach, LTE mobile routers are placed in each of the cell-site locations. These routers have instrumented VoLTE clients which are programmed to periodically call other LTE mobile routers in the other cell-site locations and push certain pre-loaded audio data. After each automated call, both routers push heavily instrumented VoLTE instrumentation data to the VoLTE machine learning analyzer function in the cloud. Similar data may also be obtained from User Equipment (UE) that use the operator's VoLTE clients. Figure 1 below illustrates other data sources that are part of the date pipeline.

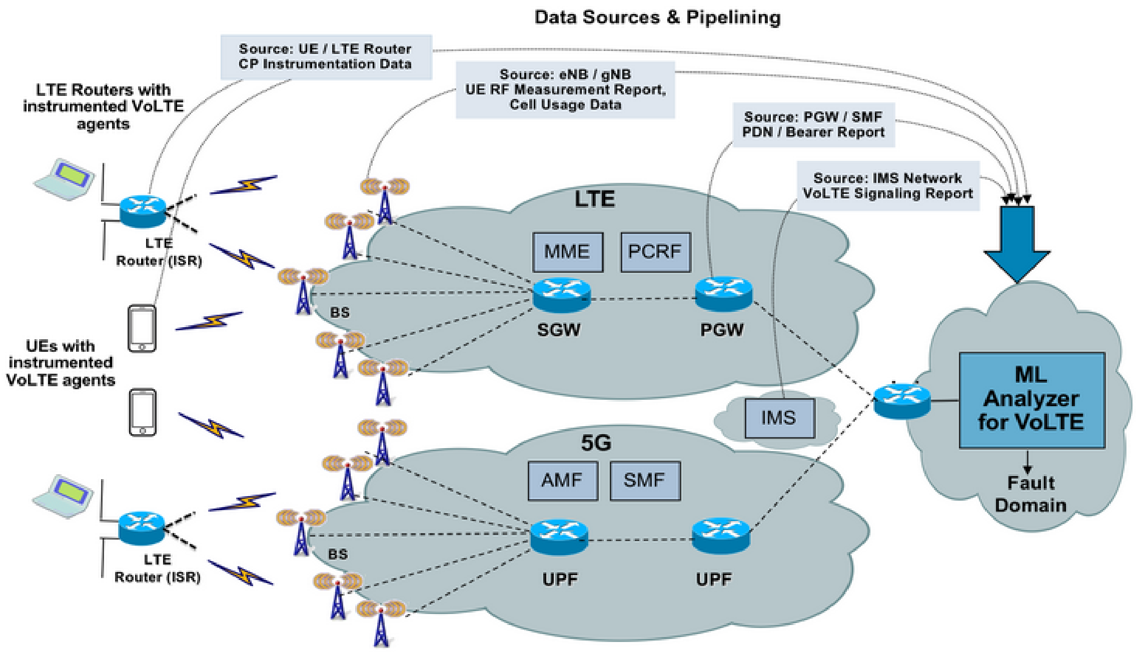

Figure 1

Data collected from various sources is pushed to the VoLTE machine learning analyzer. The data includes the following.

- Customer Premises Equipment (CPE) Instrumentation data from UE/LTE router
- UE Radio Frequency (RF) measurement report and cell usage data from eNB/gNB
- PDN bearer report from the Packet Data Gateway (PGW) / Session Management Function (SMF)
- VoLTE signaling report from IMS

As illustrated in Figure 2 below, data may be classified per VoLTE call data (from the UE and IMS), per bearer data (from the UE, eNB/gNB and PGW/SMF) and/or global data (from the eNB/gNB, PGW/SMF). For example, global data from eNB/gNB may be the total number of UEs attached to the cell. However, the analyzer may require the data on a per VoLTE call basis. Therefore, data may be correlated and normalized on a per VoLTE call basis.

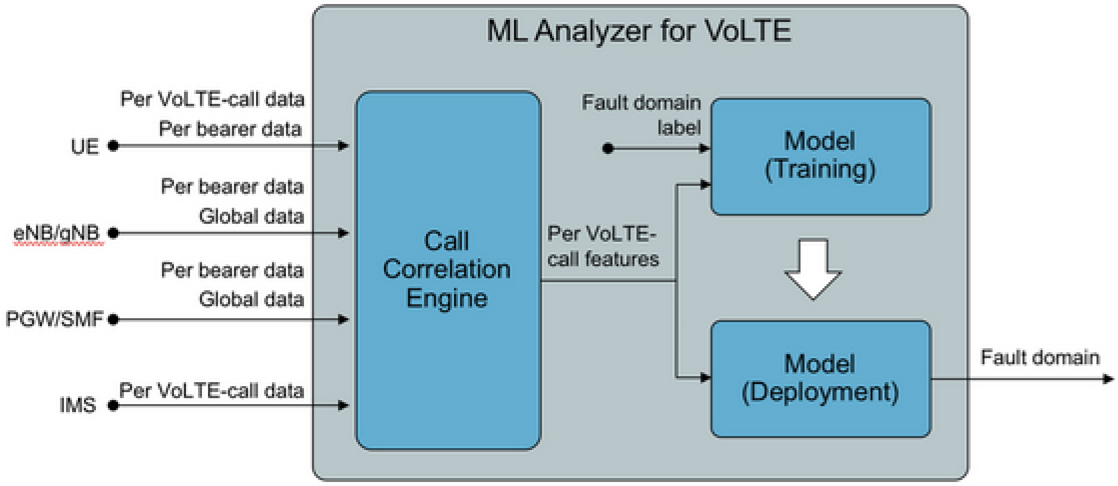

Figure 2

The aim of the analyzer is to identify one or more of the following fault domains. This list may be made more granular by levering the more granular data collected from the various sources.

- UE related issues
- Received Signal Strength Indication (RSSI) / Reference Signal Received Power (RSRP) / Reference Signal Received Quality (RSRQ) related issues
- Radio Access Network (RAN) resource related issues
- PGW related issues
- IMS related issues

Figure 3 below illustrates a workflow that describes training and deployment of a machine learning algorithm for fault domain prediction.

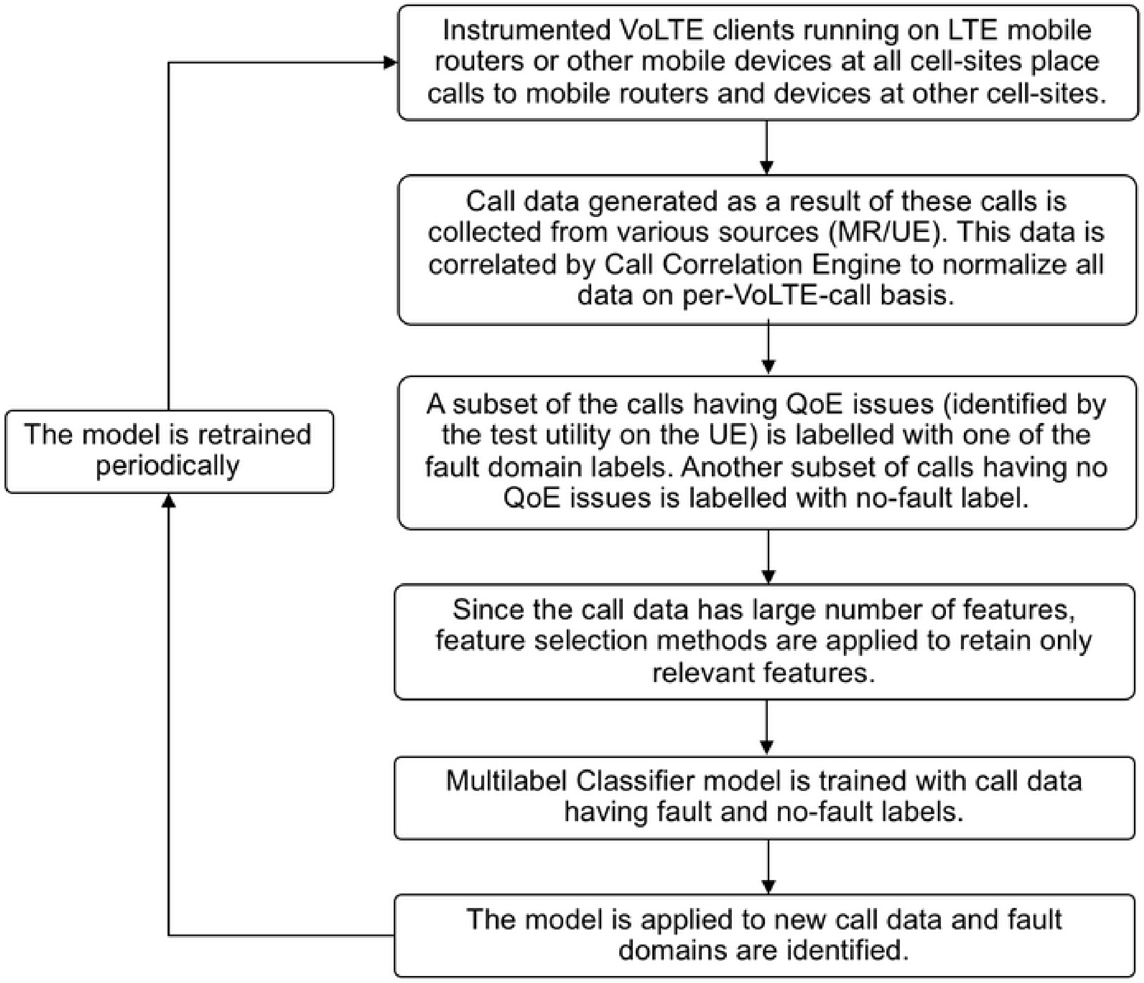

Figure 3

Wherever possible, fault labels for calls with Quality of Experience (QoE) issues may be generated using a method of injecting faults into the network. This is possible in a controlled environment without live users. In an example method, initially the first type of fault is injected into the network. Second, the instrumented VoLTE clients make calls to other clients. Third, the generated call data is labeled with the injected fault type. Fourth, the process is repeated for all other fault types. Fifth, the process is also repeated with no fault injected into the network so that call data with no QoE issues is also included for model building. When faults cannot be injected into the network (e.g., a live network), labels may be identified using manual troubleshooting before the model is trained.

Described herein is an approach for collecting specific instrumented data from a UE (or a mobile router fixed in cell-site location), eNB/gNB, PGW/SMF/UPF and IMS core network. An LTE based mobile router may place calls to other LTE mobile router(s) periodically to proactively measure the VoLTE performance. PDN/Bearer performance metrics may be obtained from the PGW/UPF/SMF functions. RTP sender reports may be intercepted on the UE to UE data plane. Data received from various sources described above may be correlated and normalized on a per call basis. Call data may be labeled with one of multiple fault domains in case of calls with QoE issues and with no-fault labels in case of calls with no QoE issues. Feature selection methods may be applied on the labeled data to extract only relevant call features. A multi-label classifier machine learning model may be trained based on the labeled call data and deployed on new calls for predicting fault domains in case of calls with QoE issues.

VoLTE signaling plane instrumentation may be obtained from the VoLTE client on UE (or a mobile router in the cell-site). This may include the following features:

- Call Setup Delay: Dial to ring back tone delay, where larger values indicate that the user will hang up the call.
- Dial to Ring Delay: Between invite to 180 (ringing), a dedicated bearer setup takes place and that involves Rx signaling from the IMS to the Policy and Charging Rules Function (PCRF) and Gx signaling from PCRF to PGW. Once the phone rings, it depends on when the user picks up the phone.
- Retransmission of each of the Session Initiation Protocol (SIP) messages and the associated round-trip delay.
- Invite Packet size: The size of the Invite message may be large due to inclusion of Session Description Protocol (SDP) and other parameters so it may result in fragmentation.
- Post Pickup Delay: The delay between the time the callee picks up the receiver and the time the caller receives an indication of the same.
- Post Dial Delay: Delay between the Invite and first provisional response. It may cause retransmission or call failure if the delay is substantial.
- Mid-Call Signaling: The call may activate additional SIP features.
- Delays should be within the acceptable limit for qualifying the service as “good.”
- Additional Key Performance Indicators (KPIs) from the PGW and IMS core (user calls):

- Number of calls that lasts less than 10 seconds. This is an indication of a problem.
- Average number of calls from each cell-site
- Peak Call Count
- Timeouts reaching the Proxy-Call Session Control Function (P-CSCF)
- Current (e.g., today) SIP/RTP bytes per call.

The UE Measurement Reports may be obtained from the eNB/gNB. The Measurement Report may be triggered when the measured value crosses (e.g., goes higher or lower than) a certain target value. The eNB sends a Radio Resource Control (RRC) message indicating what kind of items are to be measured and the UE sends an RRC message that carries the result of the measurement.

The Channel Status Indicator may comprise three LTE Quality Indicators (e.g., Channel Quality Indicator (CQI), Precoding Matrix Indicator (PMI), and Rank Indicator (RI)) and serve as a benchmark for transmission quality in the downlink. The CQI contains information sent from a UE to the eNB to indicate a suitable downlink transmission data rate (e.g., a Modulation and Coding Scheme (MCS) value). PMI may determine how the individual data streams (called layers in LTE) are mapped to the antennas. RI is a channel rank that indicates the number of layers and the number of different signal streams transmitted in the downlink. PMI and RI are for multiple-input and multiple-output (MIMO) pre-processing and ensure that the correct rank and precoders that will maximize throughput are set.

Parameters for cell selection/reselection may include RSRP and RSRQ, which are key measures of signal level and quality for modern LTE networks. In cellular networks, when a mobile device moves from cell to cell and performs cell selection/reselection and handover, it has to measure the signal strength/quality of the neighbor cells. In an LTE network, a UE measures two parameters on the reference signal: RSRP and RSRQ. RSRP may also be used to estimate the path loss for power control calculations.

Cell usage conditions may be obtained from the eNB/gNB. Table 1 below illustrates the basic cell configuration parameters upon which eNB performance is dependent.

Parameter	description
Cyclic Prefix	Used to determine the total number of OFDM symbols within one slot.
Downlink System Bandwidth	This parameter indicates the system bandwidth in the downlink, which is used to determine the frequency domain location of the downlink physical channel as well as downlink frequency allocation.
Uplink System Bandwidth	This parameter indicates the system bandwidth in the uplink , which is used to determine the frequency domain location of the uplink physical channel as well as uplink frequency allocation.
Cell Max Transmit Power	This parameter specifies the maximum available transmit power.
Cell Transmit Power	This parameter specifies the used transmit power.
Cell-specific Reference Signals Power	This parameter specifies the absolute power value of the cell reference signal for each resource element.
DRX Cycle for Paging	t his parameter specifies the DRX cycle for paging purposes.
nB	nB is used to derive the paging frame and paging occasion,
The Parameter to Detemine BCCH Modification Period	The purpose of this constraint is to ensure that all the UEs being in idle state can monitor the system broadcast change message.
TAC	it indicates a tracing area in a PLMN. It is used to manage the UE location and find the desired UE.
PCI	Used for searching a specific Cell
Neighbouring Cell	The neighboring cell planning aims to ensure voice quality and performance of the entire network as the UEs on the cell edge can be handed over to their neighboring cells with the best signals
Frequency	Ensure that two cells with great overlapped coverage should better not use the same frequency resources

Table 1

Table 2 below illustrates various eNB statistics and counters.

Packet statistics	Ethernet Packets
	Ethernet Packets Per VLAN
	AIR MAC Packets
	AIR RLD Packets
	PDCP Packets
RRC	RRC Connection Establishment
	RRC Connection Recofiguration
	RRC Connection Re Establishemnt
	RRC Connection Release
	RRC Connection Number
	RRC Connection Setup Time
	RRC Connection
	RRC Connection Re Establishment Time
ERAB	E-RAB Setup
	E-RAB Setup Add
	E-RAB Setup Time
	E-RAB Erase Request
	E-RAB Erase
	E-RAB Modify
	E-RAB Release Request

	E-RAB Release
	E-RAB Session Time Per Cell
	E-RAB Session Time per QCI
	Active ERAB Number
	E-RAB QCI Per PLMN Rejected
HO EUTRAN	Intra eNodeB Handover
	X2 Out Handover
	X2 In Handover
	S1 Out Handover
	S1 In Handover
	Handover Time
	Measurement Results of Source Cell
	Measurement Results of Target Cell
CSI	Call Fail
MRO	MRO RLF Classificaiton
	MRO RLF at RRC Connection
VoLTE	VoLT Handover
GTP	GTP Sequence Number per QCI
	GTP Sequence Number per eNodeB
	GTP Forward Traffic
SRB	Cell PDCP SDU Bit Rate
DRB	Active UE Number
	Packet Delay
	Packet Drop rate
	Packet Loss Rate
	IP Lateny
RRU	PRB Usage
	Total PRB Usage
	Cell Unavailable time
	PRB Full Utilization

S1SIG	UE Associated Logical S1 connection establishment
Paging	Paging
Overload Protection	Denied Call by overload protection
Power	Power
	RNTP of Own Cell
	RSSI of each path measured by MAC
RA	Random Acess Preambles
	RACH Usage
HARQ	Transmission BLR
AMC	MIMO
	MCS
	DL MCS
	DL Layer
	DL Wideband CQI
	DL PMI
	DL RI
	DL Ack-Nack DTX Ratio
Timing Alignment	Timing Alignment
	Timing Advance Based UE Limitation in connected
	Timing Advance Based UE Limitation in Initial Attach
IOT	Uplink IOT Level
Load Balancing	Load
	Load Balancing Handover
	Idle Load Balancing
	Redirected by Load Balancing
Traffic distribution	Throughput distribution
	Delay distribution

	Drop Distribution
	CQI Distribution
eMBMS	MBMS eNB Signaling
	MBMS eNB Sync
	MBMS cell Sync
Aggregate Maximum Bit Rate	UE-AMBR Override
UE Category	UE Category
KPI	Please See Section C below

Table 2

eNB KPIs may include accessibility KPIs, retainability KPIs, mobility KPIs, integrity KPIs, utilizations KPIs, availability KPIs, and traffic counters. Accessibility KPIs may be used to properly measure whether services requested by users can be accessed in a given condition, and may also refer to the quality of being available when needed by users (e.g., user request to access the network, access the voice call, data call, etc.). Accessibility KPIs may include the RRC setup success rate, the E-UTRAN Radio Access Bearer (ERAB) setup success rate, and the call setup success rate.

Retainability KPIs may be used to measure how the network keeps the user's possession or is able to hold and provide services for the users. Retainability KPIs may include call drop rate service and call drop rate.

Mobility KPIs may be used to measure the performance of the network which can handle the movement of users and still retain the service for the user (e.g., handover). Mobility KPIs may include intra-frequency handover out success rate, inter- frequency handover out success rate, and Inter - Radio Access Technology (RAT) handover out success rate (e.g., LTE to Wideband Code Division Multiple Access (WCDMA)).

Integrity KPIs may be used to measure the character or honesty of a network to its user (e.g., throughput, latency served to the users). Integrity KPIs may include E-UTRAN IP throughput, IP throughput in downlink, and E-UTRAN IP Latency.

Utilization KPIs may be used to measure the utilization of a network and whether the network capacity has reached its resource. Utilization KPIs may include mean active dedicated Evolved Packet System (EPS) bearer utilization.

Availability KPIs may be used to measure how the network keeps the user's possession or is able to hold and provide the services for the users. Availability KPIs may include E-UTRAN cell availability and partial cell availability (node restarts excluded).

Traffic counters may include a number of different factors, including Outbound Bad Packets, Outbound Packets Discarded, Received Bad Packets, Received Octets, Received Packets Discarded, Received Unicast Packets, Received Unknown Protocol Packets, Transmitted Octets, and Transmitted Unicast Packets.

The PDN/Bearer performance report may be provided from the PGW. The performance report may include average jitter for the RTP on the Guaranteed Bit Rate (GBR) bearer, average packet delay on the GBR bearer, and average packet loss on the GBR bearer.

Table 3 below illustrates an example PDN total.

Active	The total number of active PDN sessions.
Setup	The total number of setup PDN sessions.
Released	The total number of released PDN sessions.
Rejected	The total number of rejected PDN sessions.

Table 3

Table 4 below illustrates an example bearers total.

Active	The total number of active bearers.
Setup	The total number of bearers setup.
Released	The total number of number of bearers released.
Rejected	The total number of rejected bearers.

Table 4

Table 5 below illustrates example bearers by QoS characteristics:

Active: QCI n	The total number of active bearers for QCI n. Where n is a QCI value of 1 through 9 or a QCI value of 65, 66, 69, or 70.
Non-Std QCI (Non-GBR)	The total number of active non-standard non-GBR bearers.
Non-Std QCI (GBR)	The total number of active non-standard GBR bearers

Setup: QCI n	The total number of bearers setup for QCI n. Where n is a QCI value of 1 through 9 or a QCI value of 65, 66, 69, or 70.
Non-Std QCI (Non-GBR)	The total number of non-standard non-GBR bearers setup.
Non-Std QCI (GBR)	The total number of non-standard GBR bearers setup.
Released: QCI n	The total number of released bearers for QCI n. Where n is a QCI value of 1 through 9 or a QCI value of 65, 66, 69, or 70.

Table 5

Table 6 below illustrates user plane KPI.

IP Throughput	UL/DL IP throughput
Application throughput	Application specific (FTP, RTP) UL/Dl throughput
TCP Round Trip Time	Is influenced heavily by Radio Quality
Packet Jitter	Average of deviation from network mean latency
Packet Delay UL	The time the eNB needs to forward a packet received from the Uu to S1-U interface
Packet Delay DL	The time the eNB needs to forward a packet received from the S1-U to Uu interface
Packet loss	The total number of lost packets and the time distribution of packet loss

Table 6

Media reports may be obtained by the PGW. The media reports may include bytes received, the fraction packet loss reported, packet jitter measured in seconds the total number of RTP packets lost, the total number of RTP packets received, bytes sent, packets sent, round trip time, target Bitrate, etc.

In summary, techniques are described for a machine learning based VoLTE trouble-shooting/diagnostic approach which can look at various data sources in the mobile packet core and identify the key issues by observations and correlations across data fields using machine learning techniques. It helps mobile operators to quickly identify fault domains in VoLTE calls and take corrective actions to enhance customer QoE.