Digital Transformation of Oil & Gas Fields Architecting Multi-Services Digital Private Network on 5G NR-U Model

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***Abstract* - A compelling need for Real Time decision making with detection, diagnosis & resolution of key industry related parameters from Industrial assets enabled with Digital Twins in hyper connectivity with IoT & low latency requirements as a primary driver for digitization of private industry. Focus on Industrial Revolution (IR) 4.0 with industry Digital Transformation solution is architected on Connectivity, Command, Control, Compute and Cyber Secure enabled industrial process control operations (5C Solution). 5G technology is chosen for its inherent high bandwidth capability and low latency features enabled by Multi-access Edge Computing (MEC) and cloudification architecture with virtualization-based solution. Quality of Service (QoS) and Quality of Experience (QoE) metrics with high reliability and high availability architectures are chosen as critical features. 5G New Radio – Unlicensed (NR-U) spectrum considered for realizing dense Radio Access Network (RAN) solution with Inter-site Distances (ISD) varying from 500mtrs to 1km with Rx sensitivity of upto -95dBm to enable the connectivity to distributed oil & gas field assets. 5G coverage design of the network is done with focus on interference minimization, neighbor relation management, load balancing and parameter optimization. Converged Connectivity Network with Industrial Automation Bus (IAB) based architecture is proposed to be realized with Digital Communication network Gateway (DCG) covering the functions of Operational and Information Technology (OT/IT). Oil & Gas industry's 3Rs (Rigs, Reservoirs & Refineries) with varying bandwidths - 10kbps to 1Gbps is supported by 5G NR-U RAN with Adaptive Antenna System (AAS) and beamforming technology using 4x4 Multiple Input Multiple Output (MIMO), 40/80MHz channel Bandwidth, 256 DL-QAM (Quadrature Amplitude Modulation) and latency requirements from - 100msec to 1msec enabled by MEC are met with use cases of process sensors, drones, Automated Guided Vehicle (AGV), Industrial robot (IR), Augment Reality/Virtual Reality (AR/VR) and Mission Critical Services (MCS) with highest degree of built-in cyber security.**

Keywords: Digital Private Network, 5G NR-U, Oil & Gas, Prediction plots, RAN Architecture, DRCS (Dedicated Short-Range Communications), ITS (Intelligent Transport System, Effective Isotropic Radiated Power (EIRP)

I. Digital Private Ne twork RAN realization

Dynamic Sensing, Comprehensive analytics-based domain intelligence and drive automatic control of connected mechanical systems in a network environment is essential to take precise action in response to well interpreted inputs.

Digital Private Network is proposed to be realized with 5G NR-U and WiFi6 radio access technologies to have a digital agile network infrastructure with automation and innovation focus as shown in Fig 1. Operational engagement with network operational digitization on NaaS (Network as a Service) model is proposed to aim at a responsive network to meet the demands of informatics era of Industrial transformation.

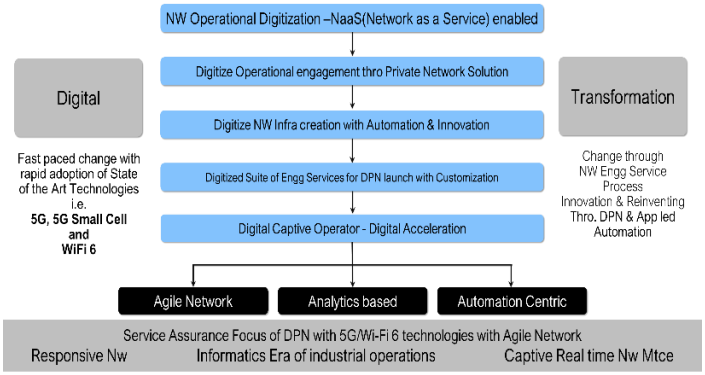

Fig 1: Need for Digital Transformation in DPN

Virtual RAN (vRAN) systems are chosen with features of efficient RRM (Radio Resource Management), PCI (Physical Cell ID), Carrier Aggregation (CA), with Zero touch enablement of configuration controls for MIMO beam management and power control.

II. Networking Layers for Digital Transformation of Oil & Gas Segments

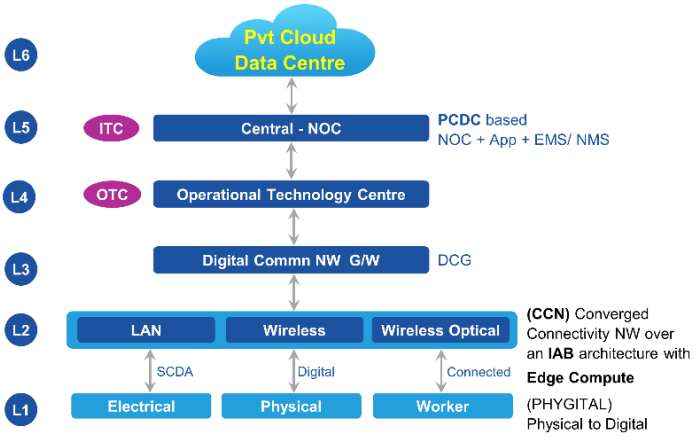

Fig 2: Layer-wise Digital Transformation for O&G

Conceptual layer-wise functional elements as shown in figure 2 is proposed to be involved in Digital Private Network (DPN) for Industrial Automation[1] involves the following

Layer 1: Digital Twin enabled Internet of Things (IoT) sensor Network, Industrial Ethernet Switch, Industrial Wireless Customer Premise Equipment (CPE)/Wireless Fidelity (Wi-Fi)

Layer 2: Industrial Local Area Network (LAN) Switches and wireless enabled IoT Gateway with 5G NR, WiFi6 and associated Optical xPON (x Passive Optical Network)

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Layer 3: Distributed wide-area 5G NR/WiFi6 RAN clusters as gateway providing hyper connectivity towards Oil & Gas (O&G) field assets in Physical (PHY) layer, Layer 2 and also to Layer 4 and above for CT/OT/IT/ST hierarchical systems (CT- Communication Technology, OT- Operational Technology, IT- Information Technology, ST – Security Technology)

Layer 4: Operation Sub System (OSS) Platforms for Communications, Control & Command Network & elements

Layer 5: IIT - Industrial IT Network in Cloud architecture-based Data Centre

III. SELECTED 5G NR - UNLICENSED BAND

Unlicensed National Information Infrastructure (U-NII) radio band announced as defined by the United States Federal Communications Commission (FCC) is followed globally as part of the NR-U spectrum used by RAN.

3GPP(3rd Generation Partnership Program) standards also advocate the NR-U as one of the RAN spectrum recommendations for releasing 5G private networks.

The following UNII specified spectrum bands are chosen for dense 5G Radio access design for industrial asset connectivity of O&G field,

TABLE I. UNLICENSED NATIONAL INFORMATION INFRASTRUCTURE (U-NII) SPECTRUM BAND DETAILS [6][7]

Name	Aliases	Freq. Range (GHz)	Bandwidth (MHz)	Max Power (mW)	Max EIRP (mW)
U-NII-2C	U-NII WW/ U-NII-2-Extended / U-NII-2e	5.470–5.725	255	250	1,000
U-NII-3	U-NII Upper	5.725-5.850	125	1 W	200 W
U-NII-4	DSRC/ITS	5.850–5.925	75	—	—

The 5G NR-U Radio Frequency (RF) channels are selected in multiples of nx40, nx80MHz to meet the varied bandwidth requirements as indicated below,

TABLE II. VARIED BBANDWIDTH REQUIREMENTS IN COMMITTED INFORMATION RATE (CIR) RANGE WITH UL/DL PERCENTAGE

Industrial End Point	CIR Range	UL%	DL%
Industrial wireless Gateway Router	300kbps to 5Mbps	70	30
Process Sensors as Digital twin for 3Rs (Rigs, Reservoir & Refinery)	50kbps to 5Mbps	90	10
HD Camera for surveillance	8Mbps	95	5
Inspection Robot/Automated Guided Vehicle (AGV)	10Mbps	50	50
Unmanned Ariel Vehicle (UAV)/Drone	10Mbps	50	50
Connected Vehicle (C-V2X)/ Autonomous vehicle	20 to 50Mbps	50	50
Smart Connected Workers (SCW) with Wearables	300kbps to 2Mbps	95	5
Smart connected workers with Mobile/Tablet	10Mbps	30	70
Smart connected workers with VR/AR Headset	50 to 100Mbps	50	50
WiFi6/5G NR-U Wireless Access Point (WAP)	100Mbps	50	50

Each O&G industrial Point-of-Presence (PoP) aggregated bandwidth to be served out of the RAN requirement is arrived at considering all the above mentioned range of CIRs to cater to different types of PoP level connectivity i,e IR, AGV, UAV, C-V2X, AR/VR, Wireless Access Point (WAP) etc., Such PoPs to be served out of a 5G NR-U gNodeB (gNB) varies from 5 to 10 over an area of 1 to 1.2sq.km. The 5G NR-U gNB based RAN is designed considering the Uplink/Downlink (UL/DL) ratio of the industrial end points. Coverage simulation modelling is done considering the above deployment densities of industrial end points to be connected and also the no. of gNBs on NR-U to be deployed for ensuring industrial Operational Area (OA) coverage.

IV. O&G FIELD ASSET COVERAGE – RAN ARCHITECTURE

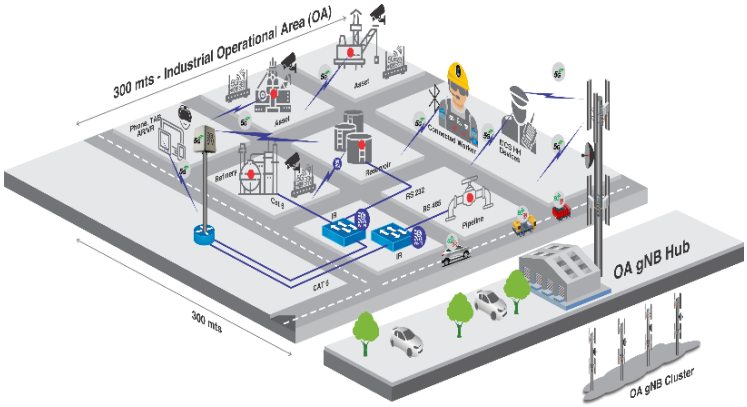

Fig 3: Macro level RAN architecture - O&G Industry operation area

Typical O&G industrial asset area as shown in Fig 3 covers 350x350mtrs with coverage area prediction target as a design criterion taken at 98.5% KPI(Key Performance Indicator). Each of the industrial asset consists of rigs (Mobile Unit and Off-plot asset), reservoir, refinery, pipeline as end points with 5G NR-U/Wifi6 enabled WAPs and to enable connectivity to SCW for MCS. Each gNB is expected to reach about 1 to 1.2sq.km to cover 3 such industrial asset areas. Each Operational RAN clusters are designed to have 30 to 50 5G NR-U gNBs having an area throughput in the ranges of 75Gbps to 125Gbps over 25sq.km to 50sq.km area.

V. FACTORS CONSIDERED FOR DESIGN & DIMENSION OF RAN

Industrial facility Coverage area considered to be ranging from 25sq.km to 50sq.km consisting of all assets like rigs, reservoirs, refineries, pipelines, SCW with MCS, AR/VR, C-V2X, Drones, and High Definition (HD) Camera surveillance.

The coverage prediction model followed as per Erceg-Greenstein (SUI). Unlicensed n46 band is considered with 3GPP specified RF Transmitter and Receiver salient parameters like 1W power output and Receiver sensitivity -95dBm. 4x4 MIMO of gNB at antenna gain of 23.7dBi and AAU of 32-channel. RF channel bandwidth considered from 40MHz and 80MHz with 256QAM. Each of the gNB is considered for a throughput from DL:2.25G/UL:1G

All gNB sites are considered to be supported through Monopole infrastructure of a maximum of 20mtrs height with corresponding gNB Antenna proposed to be installed at 18mtrs height. >=98.5% Coverage probability KPI for Industrial operational Outdoor areas.

VI. INDUSTRY STANDARD INPUT & OUTPUT SIMULATIONS AND DESIGN APPROACH USING 3D MAPS, CLUTTER, FOLIAGE & TERRAIN DATA

3D online maps source with clutter info with altitude & height, land elevation, mean sea level, sand dunes etc., with

standards class code for 5m resolution based Digital Terrain Model (DTM) maps are used as input source.

3GPP defined Propagation model is taken as Erceg-Greenstein (SUI). Beam paths for end point level dynamic beam generated by adaptive array antenna module are simulated as output.

gNB site location, antenna height, antenna direction, tilt, cell power and antenna beamforming details are considered as RAN coverage design inputs. 3D Global Information System (GIS) display simulated prediction results of Industrial end points in the planned area covering all terrain and clutter data of industrial cluster.

VII. Sample Coverage Plots for 5G NR-U

A. *Parameters Considered for 5G NR-U RAN design simulation based on 3GPP specifications fo 5G NR-U RAN parametres in 3GPP TR 38.889[2][3]:*

Parameters	Values
Area of Interest (AOI)	18 sq.km
Technology	5G NR - U - n46
Duplexing Method	TDD (Time Division Duplex)
Frequency Band (MHz)	n46 (5.4 GHz)
Channel Width (MHz)	40 & 80
SCS - Sub Carrier Spacing	30kHz
Power Per Tx (dBm)	30dbm(1W)
Diversity Support DL/UL	SU-MIMO & MU-MIMO
Scheduler	Proportional fair
Antenna Gain (dBi)	23.7dbi
EIRP (dBm)	53.7dbm
Propagation Model	Erceg-Greenstein (SUI)
RX sensitivity	-95dbm
Noise Figure	5dB
Transmission Loss	0.5dB
MIMO	4X4
QAM	256
Height of Pole considered	18m

B. *5G NR-U Typical Cell Site – Area of coverage and ISD*

Figure 1 below indicates area of coverage of 5G NR-U cell sites with 4x4 MIMO, Adaptive Antenna Unit (AAU) with BeamForming capability and MultiUser – MIMO (MU-MIMO) support. Each cell site area of coverage ranges from 0.8 to 1sq.km at -95dBm Rx sensitivity and EIRP of 53.7dB including AAU gain with an ISD of 1 to 1.2km

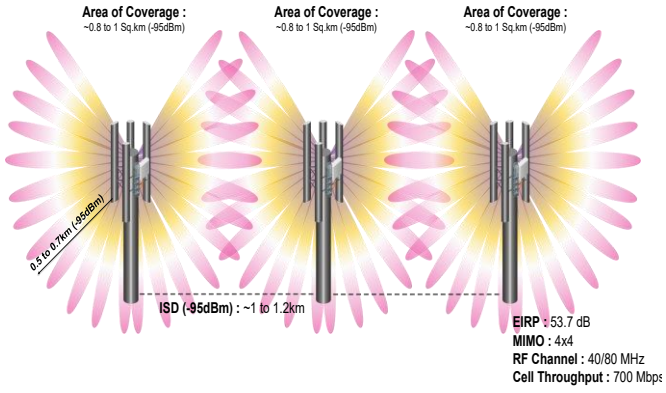

Fig 4: ISD- Area of coverage

C. *5G NR-U Prediction Plot Simulation*

The prediction plot for private networks are essential to be simulated and analyzed involving Synchronizing Signal (SS) – RSRP (Reference Signal Received Power), PDSCH CINR (Physical Downlink Shared Channel – Channel Interference to Noise Ration), UL/DL Throughput, MAPL (Maximum Allowable Path Loss).

a) Prediction Plot 5G NR-U - SS-RSRP:

As the simulation plot indicates the Maximum Cell radius as per the prediction plot is noted at 700m. Coverage KPIs of 98.5% is met with 18 gNBs. (3 Sectors) across 18 Sq Km of total coverage area at -95dBm Rx Sensitivity. Signal Degradations are observed at certain area inside the Area of interest polygon due to uneven Terrain, Clutter and Sand dunes in the region.

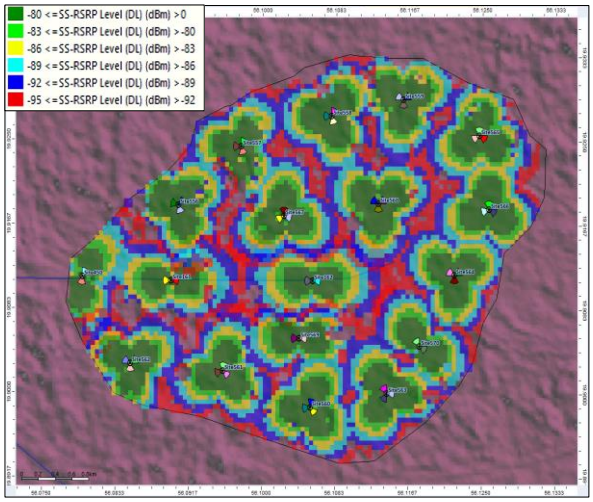

Fig 5: 5G NR-U - SS-RSRP

b) *Prediction Plot 5G NR-U - PDSCH-CINR*

Simulation plot indicates 99% of area is having more than 12 dB PDSCH-CINR, which is a benchmark criteria for cellular licensed spectrum dense 5G networks.

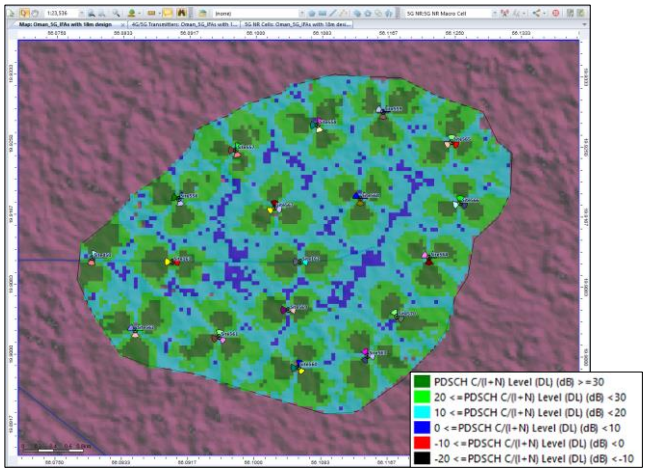

Fig 6: 5G NR-U - PDSCH-CINR

c) *Prediction Plot 5G NR-U Downlink Throughput*

Considering the bandwidth requirements to be met from a PoP perspective, the selection of 40MHz RF channel is considered for simulation of downlink throughput requirement for assessing area throughput after ensuring coverage criteria simulation being met as above. The capacity simulation plot for RAN indicates 500Mbps max DL throughput achieved within a perimeter of 200mtrs from NRU gNB and min of 100Mbps at cell edge of upto 750mtrs. This simulation is in-line with industry standard licensed spectrum having same comparable RF channel width.

Another simulation with selection of 80Mhz as RF channel has also been attempted to assess the capacity design to meet futuristic needs for all types of Industrial end point services mentioned above. The capacity simulation plot for

RAN indicates 700Mbps max DL throughput achieved within a perimeter of 100mtrs from NR-U gNB and min of 200Mbps at cell edge of upto 600mtrs. This simulation is in-line with industry standard licensed spectrum having same comparable RF channel width.

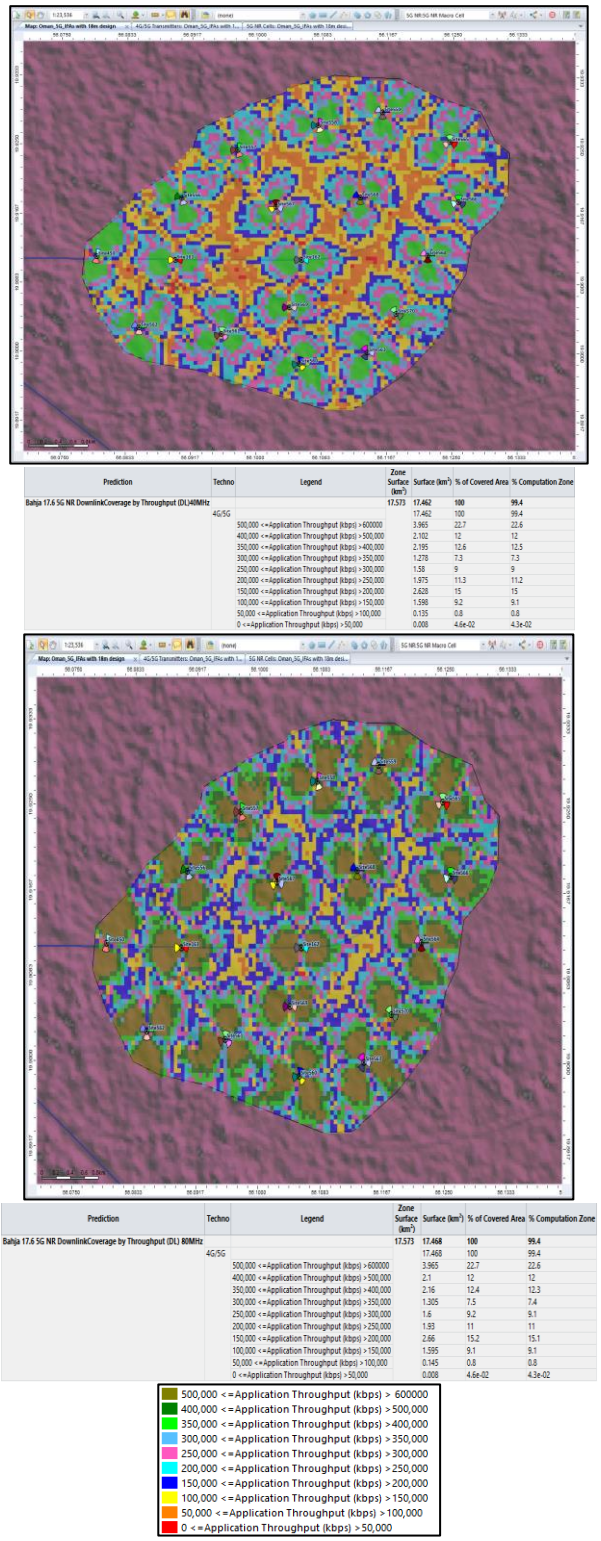

Fig 7: 5G NR-U Downlink Throughput - RF Channel Bandwidth: 40MHz & 80MHz with Legend

d) Prediction Plot 5G NR-U Uplink Throughput

The capacity simulation plot for RAN in uplink with channel bandwidth of 40MHz indicates 300Mbps max UL throughput achieved within a perimeter of 200mtrs from NRU gNB and min of 30Mbps at cell edge of upto 750mtrs. This simulation is in-line with industry standard licensed spectrum having same comparable RF channel width.

The capacity simulation plot for RAN in uplink with channel bandwidth of 80MHz indicates 400Mbps max UL throughput achieved within a perimeter of 100mtrs from NRU gNB and min of 50Mbps at cell edge of upto 600mtrs. This simulation is in-line with industry standard licensed spectrum having same comparable RF channel width.

This indicates 5G NR-U model for coverage and capacity design in both Downlink and Uplink has good spectral efficiency based compliance to the targeted design criteria in comparison to licensed sub 6GHz spectrum band of operation for corresponding gNB

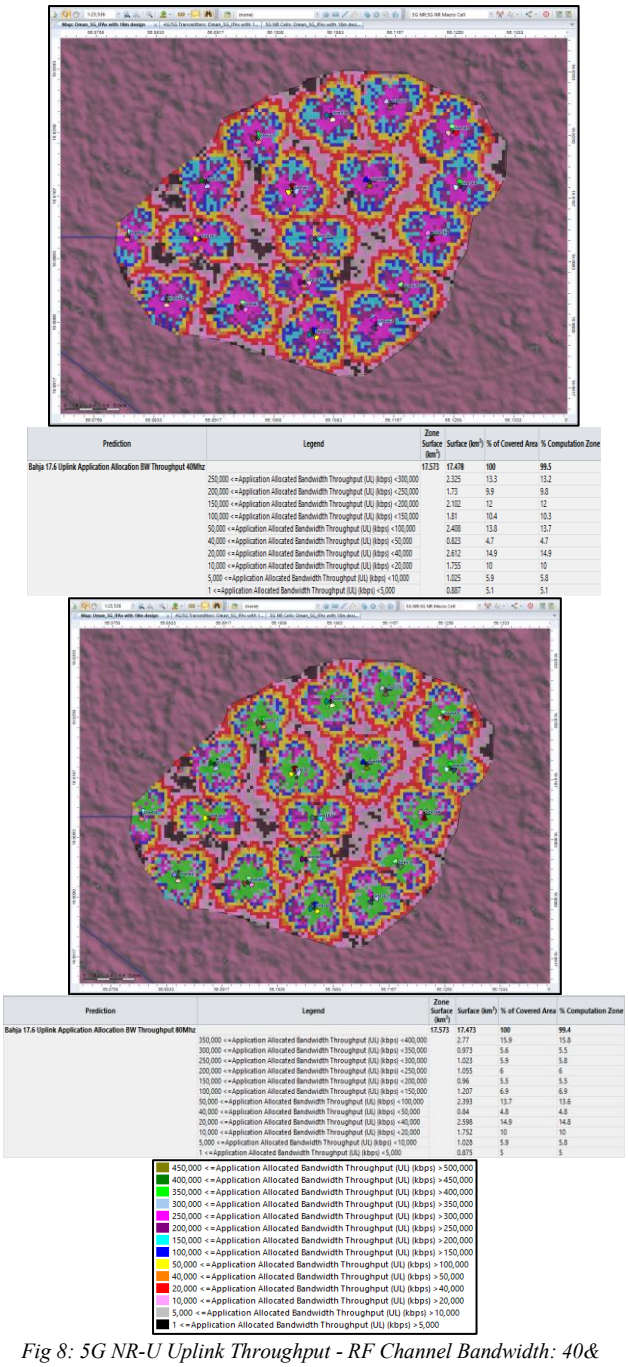

Fig 8: 5G NR-U Uplink Throughput - RF Channel Bandwidth: 40& 80MHz with Legend

e) Prediction Plot 5G NR-U – MAPL - Margin

Simulation plot indicate -128.81 dB Path loss at cell edges of 612mtrs with coverage and capacity criteria met at targeted KPIs with a sufficient margin of 10dB for 5G NR-U based RAN network design involving a cluster of 18 gNBs

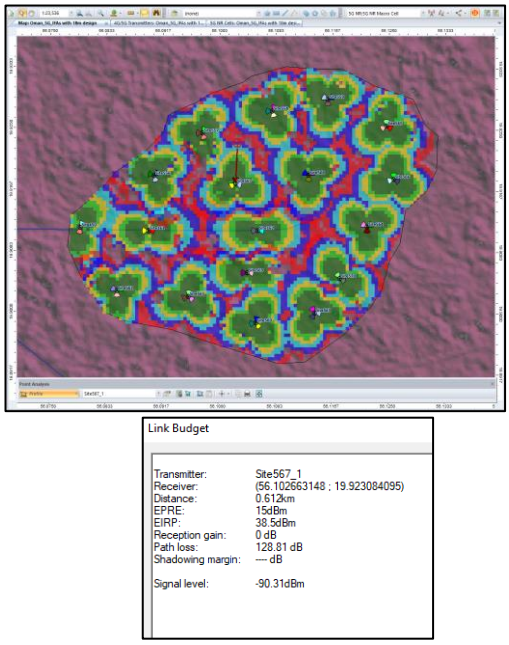

Fig 9: 5G NR-U DL Pathloss

f) 5G NR-U RAN Design Area throughput Coverage and Capacity Summary:

Area throughput of 40+ Gbps Capacity of RAN is achieved across an area of 18sq.km with 18 gNBs each having a site (3 sector with 4x4 MIMO) throughput of 2.25Gbps. Coverage KPI requirement of 98.5% for entire RAN cluster of 18gNBs is met with Rx sensitivity of -95dBM which is benchmark for licensed 5G cellular network.

VIII. Use Cases – Industry 4.0 – Oil & Gas Pvt Networks

With all the coverage and capacity simulations as above, all the following use cases as shown in Fig 10 involving variable Bandwidth of UL/DL are adequately supported to cater to the industrial end point device like Rig, Reservoir and Refinery connectivity requirements like Drones, AGV, Video surveillance, AR/VR, Industrial sensors, Industrial Robot, MCS etc., including operational Head Quarters (HQ) as a smart building with connectivity, control, and computational requirement[4].

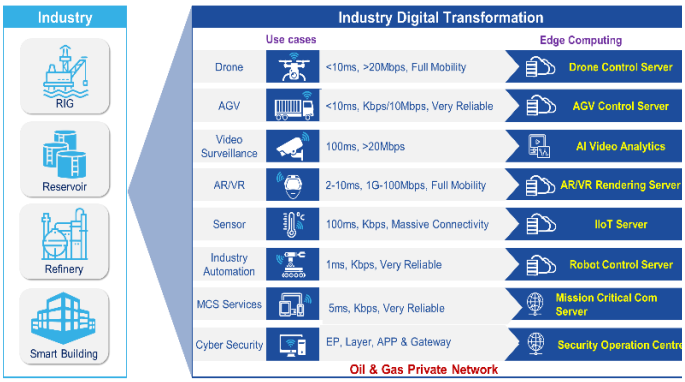

Fig 10: Oil & Gas sector Use cases

Drones are used to inspect industrial operational area infrastructure like pipeline, electrical transmission lines etc. from a remote location. C-V2X enables vehicle to vehicle, Vehicle to infra, vehicle to network communication and enables ADAS (Advanced Driver Assistance System) with 5G enabled in-vehicle On-board unit (OBU) with the help of Roadside units (RSUs) enabled with 5G NR-U cum WiFi 6 air interface support.

5G NR-U cum WiFi 6 enabled Video surveillance cameras are also catered as part of connectivity solution to monitor industrial facility sites and to identify and capture Health, Safety & Environment (HSE) violations. 5G NR-U cum WiFi 6 enabled AR/VR headset and camera as a use case are supported from bandwidth requirements as a part of simulation. These AR/VR headsets are a part of SCW wearables.

Process sensors from IR 4.0 with corresponding digital twins are also supported from coverage and capacity requirement from the 5G NR-U deployments to capture the oil and gas assets data such as pressure, temperature, valve position etc. and configure remote field devices. Inspection Robots with built-in 5G NR-U cum WiFi 6 enabled air interface are also supported from latency bandwidth requirements to investigate or fix issue in hazardous/danger Zone areas.

Mission Critical Services like group call, emergency calls, multicast, unicast with voice, video and messaging applications requiring different bandwidth and latency are also supported as a part of coverage and capacity simulation of RAN network on 5G NR-U.

Summary

The paper summarizes the adoption of 5G NR-Unlicensed spectrum in 5.470GHz to 5.925GHz for realizing digital transformation enabled private 5G RAN for Oil and Gas fields with the key attributes of coverage and capacity criteria being met as concluded with the prediction plot simulation results, thus reinforcing the capability of 5G NR-U as a viable and technically feasible alternative to 5G Licensed spectrum.

References

[1] "Achieve the full potential of your oil & gas assets INTELLIGENT ACTION FROM RESERVOIR TO REFINERY" By Sensia Global.

[2] 3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Study on NR-based access to unlicensed spectrum; (Release 15 - 3GPP TR 38.889 V0.0.2 (2018-05))

[3] 3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Study on NR-based access to unlicensed spectrum (Release 16- 3GPP TR 38.889 V16.0.0 (2018-12))

[4] 5G; Service requirements for the 5G system (3GPP TS 22.261 version 16.14.0 Release 16)

[5] "Private 5G Mobile Networks for Industrial IoT" By Qualcomm - AUTHOR: GABRIEL BROWN, PRINCIPAL ANALYST, 5G, HEAVY READING

[6] "A Survey on Industry 4.0 for the Oil and Gas Industry: Upstream Sector" - Olakunle Elijah, (Member, Ieee), Pang Ai Ling, Sharul Kamal Abdul Rahim, (Senior Member, Ieee), Tan Kim Geok, (Senior Member, Ieee), Agus Arsad, Evizal Abdul Kadir, (Member, Ieee), Muslim Abdurrahman, Radzuan Junin, Augustine Agi, And Mohammad Yasin Abdulfatah.

[7] "What's New With Unlicensed National Information Infrastructure (U-NII)" - Aole Wilkins