

The background of the slide is a photograph of four firefighters in full protective gear, including helmets and oxygen tanks. They are standing in front of a fire at night, with bright flames and smoke visible. The firefighters' jackets are dark with reflective yellow and orange stripes. One firefighter's jacket has 'OVD' written on the back. The scene is illuminated by the fire and emergency lights, creating a dramatic and high-contrast environment.

QOS TREATMENT OF PPDR TRAFFIC IN PUBLIC MOBILE NETWORKS

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TNO innovation
for life

TNO 2018 R11609-B

PROJECT DATA

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HET NIEUWE MELDEN (NL)

De wereld verandert continu. Technologische ontwikkelingen en nieuwe toepassingen daarvan in de maatschappij volgen elkaar in rap tempo op. Nieuwe communicatiemiddelen tussen mensen onderling, met bedrijven en de overheid zorgen voor nieuwe mogelijkheden voor het melden van ongevallen en noodsituaties.

Het Ministerie van Justitie en Veiligheid, de hulpverleningsdiensten (in de vorm van de Landelijke Meldkamer Samenwerking) en TNO onderzoeken samen hoe de overheid zich slimmer kan organiseren en beter gebruik kan maken van de kansen die nieuwe communicatievormen bieden voor het melden van veiligheidsincidenten.

De kennis die deze onderzoeken oplevert, draagt eraan bij om nu en in de toekomst burgers in nood sneller en efficiënter te helpen en de ambulancezorg, brandweer, marechaussee en politie beter te faciliteren bij hulpverlening en bestrijding van crisis en rampen.

Meer informatie is te vinden op <http://www.tno.nl/hetnieuwemelden>

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INTRODUCTION BACKGROUND

- › There is a growing need for a future solution in the form of mobile broadband services for mission-critical Public Protection and Disaster Relief (PPDR) purposes because various mobile information services and applications are quickly becoming essential in daily operations as well as under more severe conditions. The current and upgraded C2000 communication system cannot support such needs.
- › In various countries including the Netherlands the interest in hybrid solutions, involving 3GPP standardized commercial mobile networks is growing. More specifically, TNO recommended in 2017 [1] to leverage the existing constellation of cellular infrastructures in the Netherlands in any future national solution.
- › A particular concern of such infrastructures and offered services is that they do not have the level of resilience (against physical strains as well as traffic congestion) that is required for mission critical operations.
- › It is therefore important to get a better understanding of the vulnerability, in terms of Quality of Service (QoS), of PPDR related communication services via public mobile networks, in the presence of non-PPDR background traffic. A particularly relevant situation is when such a network is in a (near) congested state, at least locally. Such a state could be applicable in case of unplanned emergencies and disasters. Moreover, we want to assess to what extent the existing (4G based) QoS prioritisation mechanisms can reduce such vulnerabilities.

INTRODUCTION

PPDR CONTEXT (DUTCH)



- › A (major) incidence attracts a large number of
 - › PPDR personnel, as well as
 - › Public audience
- › During such events
 - › PPDR users need reliable communications
 - › Different services including mission critical ones need to be supported
 - › The background traffic load (communications by the public audience) also increases

INTRODUCTION

PPDR CONTEXT

Category	Present in incident area	Present in surrounding area
First responders	200	96
First response vehicles (including command centre COPI)	63	63
Surrounding population	1500	Not applicable

Remarks:

- Numbers are indicative
- The incident described has a high degree of severity and has never occurred in The Netherlands to date, but could take place theoretically.
- The incident area is a stretch of a national road (N322) of about 1 km in length. The surrounding environment is the area indicated on the map. On the map we see clusters of vehicles at important entry points (e.g. staging areas of ambulances)

INTRODUCTION

RESEARCH QUESTION

*) 3GPP is explained in the Annex

- › Currently, public mobile networks are used to provide non-mission critical services to *Public Protection and Disaster Relief* (PPDR) users.
- › Such PPDR traffic is currently treated as background traffic, but with a contractually agreed (slight) QoS differentiation (not considered in this study).
- › 3GPP* 4G compatible networks are able to provide specific QoS treatment to PPDR services to a certain extent through [1]
 - › Access Control Prioritization
 - › Allocation and Retention Priority (ARP)
 - › Differentiated Scheduling
- › Research questions:
 1. To what extent is the QoS experience of PPDR traffic in 3GPP-4G standardized networks affected in a (near-) congested network condition in case this traffic is treated in the same way as the background traffic?
 2. To what extent can the QoS experience of PPDR traffic in such a network condition be improved by actively using the available QoS instrumentation in such networks (4G)?
- › In this study, we will focus only on **uplink** radio access network communications because for PPDR users the availability of the uplink channel is more important compared to many other user categories while at the same time uplink is more sensitive to congestion in a mobile network.

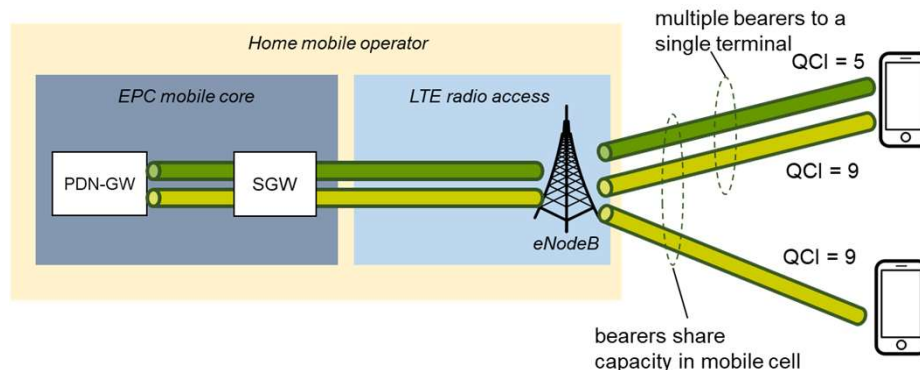
OBJECTIVE

- › The main goal of this study is the following:
 - › To achieve a better understanding of the quality of service (QoS) experienced by PPDR traffic in 4G compatible public mobile networks in a congested traffic scenario, a situation which could apply in cases of emergencies and disasters:
 - › When PPDR traffic and background traffic are equally treated by the MNOs
 - › When PPDR traffic is prioritized over background traffic
- › In achieving a better understanding, simulations have been conducted using available 4G based QoS models and various (simplified) assumptions on background and PPDR traffic. Therefore results presented here do not cover the entire problem space. They do improve our understanding of certain effects but should also be considered as theoretical and highly indicative.

DEFINITIONS AND EXPLANATION

QUALITY OF SERVICE IN CELLULAR NETWORKS

- › Bearers are logically separated connections that extend from the terminal to the PDN-GW in the mobile core network
- › Bearers allocation and retention are governed by user's QoS profile such as Allocation and Retention Priority (ARP) and QoS Class Identifier (QCI)
 - › ARP affects bearer **admission control** and potential dropping at the time of congestion
 - › QCI affects **resource scheduling** to the admitted calls
- › The actual implementation of ARP and QCI depend on Vendor and Operators choices
- › In this work we have made certain possible realistic choices regarding admission control and resource scheduling



DEFINITIONS AND EXPLANATION

ADMISSION CONTROL & RADIO RESOURCE SCHEDULING

- › Admission control
 - › Whether or not a particular call is accepted in the network at a particular time is defined by this policy
 - › It plays an important role in congested network scenarios as it defines which calls will be blocked
- › Radio resource scheduling
 - › After a call gets admitted to the network, it involves in dynamic sharing of radio resources (Physical Resource Blocks, PRBs)
 - › The resource scheduling depends on several factors, such as
 - › Type of the service
 - › Available resources
 - › Minimum acceptable throughput for the service
 - › Radio condition of the user (e.g. ratio between signal and interference plus noise (SINR))
 - › Number of active calls

SERVICE CATEGORY

- › We have considered two major classes of services, namely
 1. *Conversational* services, and
 2. *Upload* services
- › Conversational services can be further classified into following subgroups:
 - a) Voice calls, and
 - b) Video calls (e.g. Skype, WhatsApp)
- › Similarly, Upload services can be further classified into following subgroups:
 - a) Data upload* (e.g. email, location update, images, photos), and
 - b) Video upload (e.g. YouTube uploads)

*Everything which is not video is considered data in the upload service category.

TRAFFIC MODELLING

- › In this study, we have used the following reports/documents among others that are listed in slide # 44.



ITU-R M.2370-0

LEWP Matrix*

Type of application + services	throughput p/s per session	use per month per user	Number of users	mobility (using while moving)	QoS
LOCATION DATA					
AV/LS data to CCC (persons + vehicles positions)	low	high	high	high	nr
AV/LS data return	medium	high	medium	high	nr
MULTI MEDIA					
Video from/to CCC for following + intervention	high	low	medium (emergency vehicles)	high	lo
Low quality additional feeds	low/medium	low (but more)	medium	high	ln

* Matrix composed by the Law Enforcement Working Party (2010-2015) [6]

BACKGROUND TRAFFIC STATISTICS (1/2)

- › Traffic distribution over different applications [2, Table 10,11]

Service	Size (PB/ month)	DL/UL ratio	$\% DL = \frac{DL}{DL + UL}$	% Global traffic in 2014
Voice	70	1:1	50	2
Video	1400	49:1	98	43
Data	1790	1.94:1	0.66	55

- › Downlink/uplink ratio by area classification [3, Figure 5]

Area	DL/UL ratio
Dense Urban	7.09:1
Rural	1.93:1

- › Video streaming and internet browsing contributed 75% of the data traffic in September 2013 of a major European MNO [2].

- › Mobile network traffic (*data only, December 2014*) in Japan [2, Table 12])

Measured traffic data rate	UL	DL	UL/DL ratio
Average data traffic rate counted on GGSN/EPC per month (Increase from the last year)	114.3 Gbit/s (+75%)	757.5 Gbit/s (+45%)	1/6.6
Average data traffic rate per subscription per month (Increase from the last year)	693.9 bit/s (+57%)	4 599 bit/s (+31%)	1/6.6

BACKGROUND TRAFFIC STATISTICS (2/2)

- › World mobile traffic statistics (download) [4]
 - › Voice = 0.231EB/month (1.41% of the total traffic)
 - › Data = 16.176 EB/month
 - › Data traffic shares: Video = 60.2%, rest 39.8%
- › Background traffic mix (download) [4]
 - › Conversational voice: 1.41%
 - › Video (Conversational & download): 59.35%
 - › Data Upload: 39.24%
- › Average conversational voice call length is 192 seconds [5]

BACKGROUND TRAFFIC ARRIVAL RATE

- › Assuming the peak cell load (10 MHz carrier): 7 Mbit/s (downlink)
- › Corresponding conversational voice traffic load (1.41%) is 98.7 kbit/s
 - › Considering a voice call packets generates 300 bits per 20 ms
 - › *Voice call arrival rates = 7 calls/s (peak)*
- › Corresponding video traffic load (59.35%) is 4,154.5 kbit/s
 - › Considering 500 kbit/s bandwidth and the UL/DL ratio (1:49)
 - › *Conversational Video call arrival rate = 0.2 calls /s*
 - › *Video (download) arrival rate = 8.1 calls/s*
- › Corresponding data traffic load (39.24%) is 2,746.8 kbit/s
 - › Considering average data session size of 200 kbit (pictures, email, browsing)
 - › *Data call arrival rate = 13.7 calls/s*

PPDR TRAFFIC STATISTICS (1/2)

Service		Arrival rate emergency situation(λ)	Average size/duration	# of users
Voice calls		2 calls/s	17 s	
Video feeds	High quality (768 kbit/s)	2 calls/hour	6 min/hour	
	Medium quality (384 kbit/s)	6 calls/hour	3 min/hour	2
	Low quality (64 kbit/s)	26 calls/hour	46 min/hour	26
Video conference		10 calls/hour	10 min/hour	10
Video file transfer		10 calls/hour	2 MB	10

Source: LEWP matrix [6]

PPDR TRAFFIC STATISTICS (2/2)

Service	Arrival rate per hour emergency situation (λ)	Size (1 kB=1000 bytes)	# of users
Location update	100,800	80B	420
PIMSync	840	5KB	420
Mobile workplace	2100	100KB	420
Incident info (text+image)	105	50KB	105
Status+location	2100	100B	420
Speed control incl. pictures	2500	40KB	50
Scanned doc	1	100KB	10
Reporting incl. pictures	10	1MB	100
Upload maps	5	50KB	5
Patient monitoring (snapshot)	20	50KB	20
Staff health monitoring	50400	1KB	420
Online database enquiry	200	2KB	22
Miscellaneous	3500	1KB	25
Total Data Uploads	162581 ~ 46 per second	2.4 kB ~ 19.2kbit	

TRAFFIC MIX PEAK HOUR

	Background				PPDR			
	Conversational		Upload		Conversational		Upload	
	Voice	Video	Video	Data	Voice	Video	Video	Data
Individual arrival rate	7/s	0.2/s	8.1/s	13.7/s	2/s	0.003/s	0.003/s	46/s
Adapted arrival rate	56/s	2.4/s	0.51/s	13.7/s	2/s	0.33/s	3.33/s	4.42/s
Adapted mix ^(*b)	0.677	0.029	0.006	0.166	0.024	0.004	0.04	0.054
Distribution	Exponential		Log-normal		Exponential		Log-normal	
Average duration/size	3.2 min	1 min	1 kbit ^(*c)	200 kbit	17 s	10 min	16 Mbit	19.2 kbit
Adapted duration ^(*a)	24 s	5 s	16 kbit	200 kbit	17 s	5 s	16 kbit	200 kbit
Coefficient of variation	N/A	N/A	3	3	N/A	N/A	3	3

- › Adapted arrival rate = 82.69
- › PPDR:Background= 0.122:0.878 = 1:7.197

^(*a) The size/length of different services has been adapted to make fair comparison in the simulator

^(*b) The change in size/length of services affects the corresponding arrival rates and consequently the mix (i.e. the ratio between different services).

^(*c) This is the upload share of a download dominant service.

TRAFFIC MIX OFF-PEAK HOUR

	Background				PPDR			
	Conversational		Upload		Conversational		Upload	
	Voice	Video	Video	Data	Voice	Video	Video	Data
Individual arrival rate	3.5/s	0.1/s	4/s	6.9/s	2/s	0.003/s	0.003/s	46/s
Adapted arrival rate	28/s	1.2/s	0.25/s	6.9/s	2/s	0.33/s	3.33/s	4.42/s
Adapted mix ^(*b)	0.603	0.026	0.005	0.149	0.043	0.007	0.072	0.095
Distribution	Exponential		Log-normal		Exponential		Log-normal	
Average duration/size	3.2 s	1 min	1 kbit ^(*c)	200 kbit	17 s	10 min	16 Mbit	19.2 kbit
Adapted duration ^(*b)	24 s	5 s	16 kbit	200 kbit	17 s	5 kbit	16 kbit	200 kbit
Coefficient of variation	N/A	N/A	3	3	N/A	N/A	3	3

- › Adapted arrival rate = 46.43
- › PPDR:Background= 0.217:0.783 = 1:3.608

^(*a) The size/length of different services has been adapted to make fair comparison in the simulator

^(*b) The change in size/length of services affects the corresponding arrival rates and consequently the mix (i.e. the ratio between different services).

^(*c) This is the upload share of a download dominant service.

CONSIDERED ADMISSION CONTROL POLICY

- › General consideration
 - › Upload calls (data and video) are always admitted
- › Conversational call specific
 - › *Scheme 0: No differentiation among PPDR and Background traffic*
 - › A new conversational voice/ video call will only be admitted
 - › If the total resource utilization (number of PRBs) at that moment including the resource required for the call in question by considering the lowest possible codec rate*, is lower than 70% of the total resources available
 - › It also means that the rest of the resources (30%) is available for upload services
 - › If the call gets admitted, it will get the highest possible codec
 - › *Scheme 1: Prioritized PPDR traffic*
 - › Background conversational calls will follow the same rule as Scheme 0
 - › PPDR conversational calls will be accepted as long as there are resources available for them by considering the lowest codec for the call in question.
 - › This means PPDR calls in this scheme call push away all the upload traffic.
 - › If the call gets admitted, it will get the highest possible codec

*Explanation on codec rate is provided on slide # 50.

CONSIDERED RADIO RESOURCE SCHEDULING POLICY

- › General policy
 - › Resource calculation based on radio condition (e.g. SINR)
- › *Scheme 0: No differentiation among PPDR and Background traffic*
 - › Conversational calls will be assigned the resources they claim, based on the current codec
 - › If the aggregated resource claim based on current codec exceeds 100%, resource assignments will be reduced fairly (both PPDR and background)
 - › Remaining resources after serving the conversational calls will be allocated fairly among upload services
- › *Scheme 1: Prioritized PPDR traffic*
 - › Conversational PPDR calls will be assigned the resources they claim, based on the current codec
 - › If the aggregated resource claim based on current codec exceeds 100%, resource assignments will be reduced
 - › Background conversational calls will be scheduled if resources are still available after serving the PPDR conversational calls
 - › Remaining resources after serving the conversational (both PPDR and background) calls will be allocated among all *upload calls* in a differentiated fashion (applying sharing weights $\gamma_{\text{PPDR}} \geq \gamma_{\text{BACK}} = 1$, respectively)

DEPLOYMENT SCENARIOS

- › *Rural environment (e.g. like the PPDR incident scenario)*
 - › *Rural Uniform:* All traffic (PPDR and background) sources are uniformly distributed in the cell. Note that a hexagonal cell is considered in this work.
 - › *Rural Hotspot:* Background traffic sources are uniformly distributed in the cell as the Rural Uniform scenario. However, PPDR traffic sources are located in a specific part (i.e. hotspot) of the cell. Note that in this work the hotspot is modelled as a circle (much smaller than the cell area) with a certain radius (See slide # 32,36 for visual impressions).
 - › *Rural Hotspot best:* Hotspot located close to the base station
 - › *Rural Hotspot worst:* Hotspot located near the cell edge
- › *Urban environment*
 - › *Urban Uniform:* PPDR and background traffic sources are uniformly distributed in the cell. While this deployment scenario is similar to the Rural Uniform scenario, the cell sizes considered in this case are much smaller than that of the Rural Uniform deployment scenario.

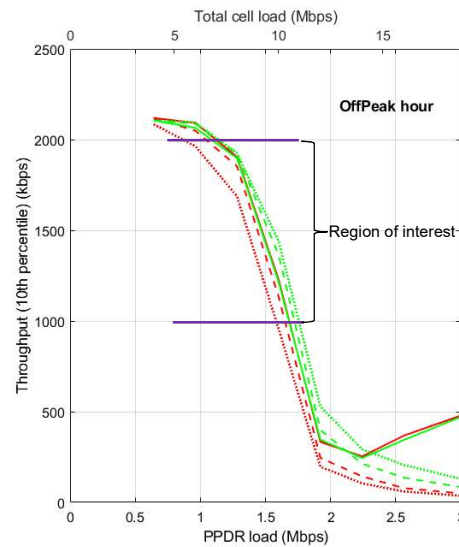
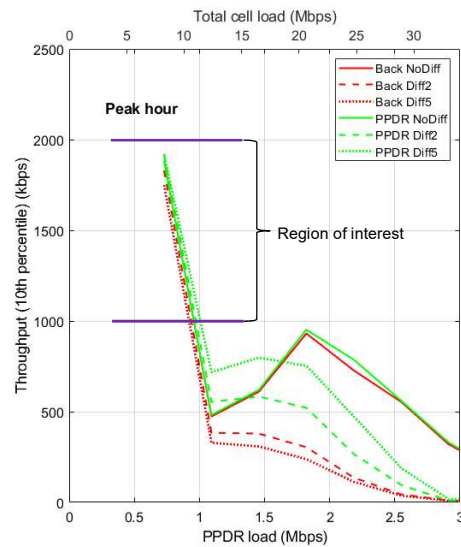
DEPLOYMENT PARAMETERS

- › *Rural* deployment
 - › Single hexagonal cell
 - › ISD: 1732 m (cell radius 1154 m)
 - › Carriers: 1 (10 MHz @ 800 MHz)
 - › Hotspot radius: 250 m (*only for the Rural hotspot scenarios*)
- › *Urban* deployment
 - › Single hexagonal cell
 - › ISD 500 m (cell radius 333 m)
 - › Carriers: 4 (10 MHz @ 800 MHz, 20 MHz @ 1800 MHz, 15 MHz @ 2100 MHz, 10 MHz @ 2600 MHz)

EVALUATION RESULTS

- › Following KPIs are considered per combination of *user class* (PPDR, background) and *service type* (conversational/voice, conversational/video, upload/video, upload/data) for different cell loads
 - › Blocking rates (i.e. the percentage of the calls that failed to admit due to the scarcity of the available resources)
 - › Average and 10th percentile (represents the cell edge users) of the user throughput experienced by (admitted) conversational calls
 - › Average and 10th percentile (represents the cell edge users) of the user throughput experienced by upload calls
- › Note that for fair comparison, we kept the traffic mix (i.e. the mix between different services) the same for all the scenarios
 - › Different arrival rates result in different cell loads
- › As we are specially interested to evaluate the QoS of PPDR traffic in a congested scenario, it is important to know the maximum cell capacity/throughput
 - › However, the actual maximum cell capacity depends on the deployment scenario
 - › Thus, we conducted a range of sensitivity analysis (please see the next slide) to get an indication on the critical cell load (i.e. the load that makes the cell congested) for different scenarios

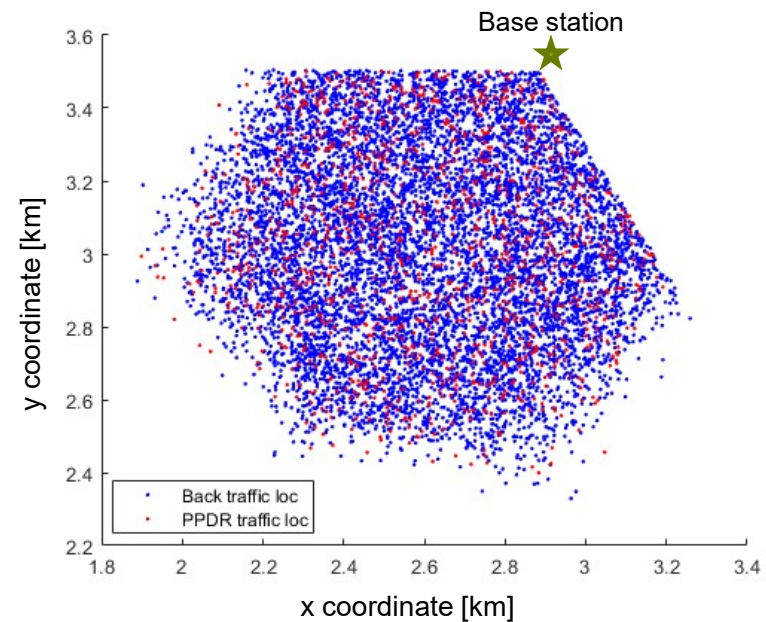
SENSITIVITY ANALYSIS TO CALCULATE CELL LOAD THAT MAKES THE NETWORK CONGESTED



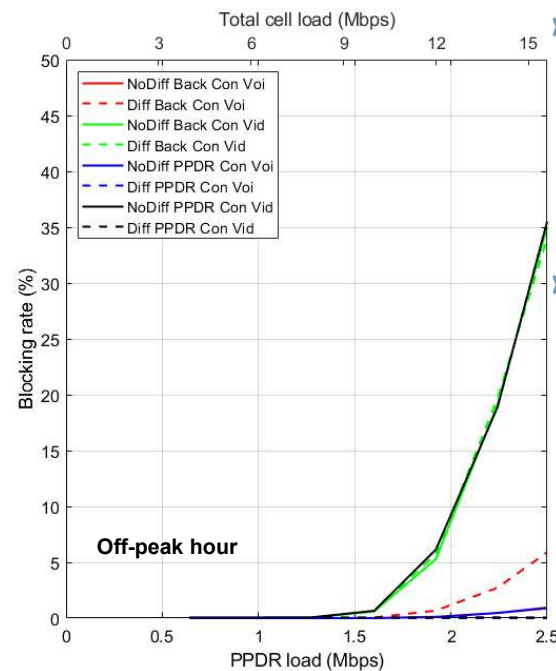
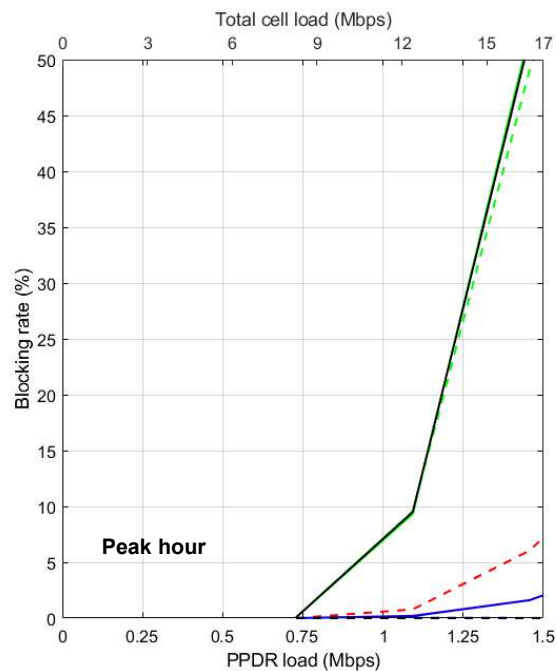
- › We conducted this sensitivity analysis by varying the cell loads (i.e. by increasing the overall arrival rates in the network).
- › A cellular operator typically plans its network such that the cell edges users (experience a throughput in the range of 1-2 Mbit/s.
- › Which give us the following values for critical cell loads
 - › *Rural*: **7-12** Mbit/s
 - › *Urban*: **70-100** Mbit/s (Figures not shown)
- › Note: The throughput curves beyond the region of interest show some irregular behaviour which needs further research. However, the load at which such irregularity appears are much higher than the loads for which cellular networks are planned.

RURAL UNIFORM TRAFFIC LOCATIONS

- › Cell is assumed to fit in a theoretical hexagonal structure.
- › Both PPDR and Background traffic locations (i.e. users) are *uniformly distributed* throughout the cell.



BLOCKING RATE



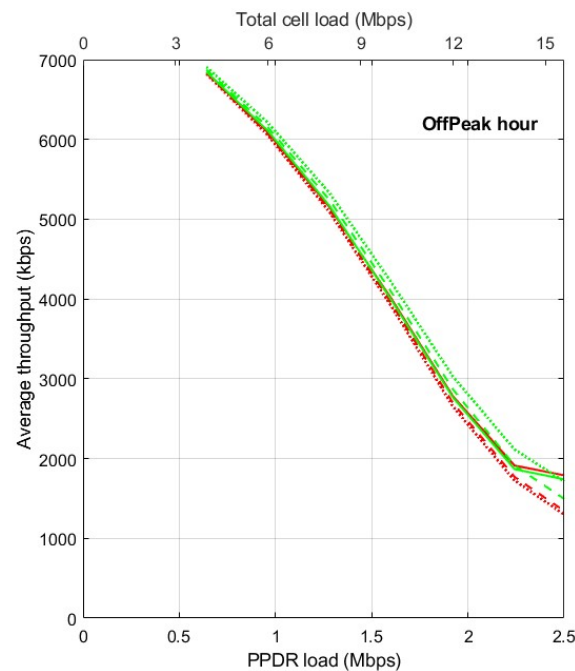
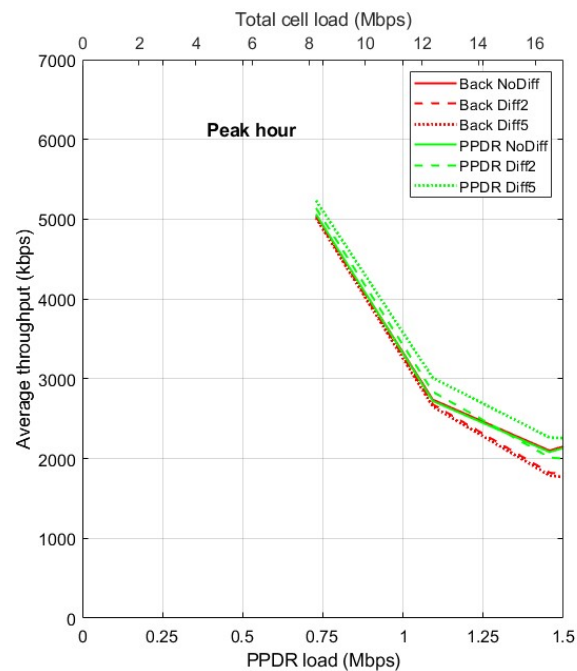
› No differentiation case:

- › Conversational video calls starts to get blocked around (and above) the critical loads;
- › Slight voice call blocking is visible for the high loads (above critical loads).

› Differentiated case (PPDR traffic prioritization):

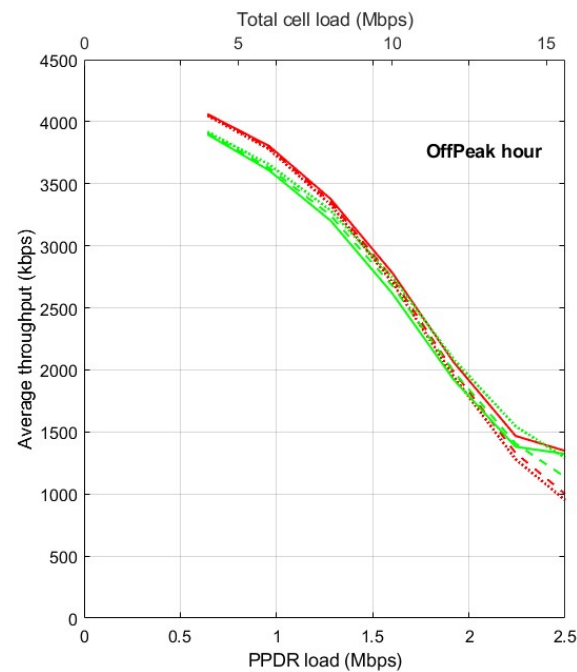
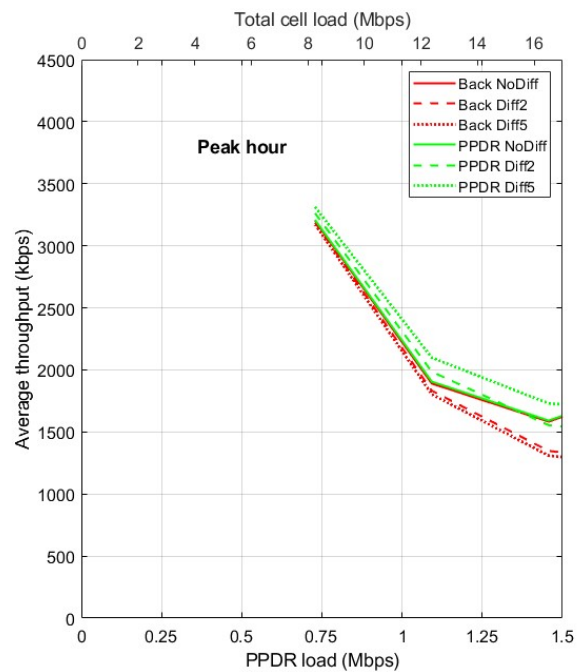
- › PPDR Conversational calls (both voice and video) are not blocked at all;
- › Background video call blocking remains same as that of the no differentiation case (note such traffic has already experienced significant blocking around the critical load);
- › Background voice call blocking increases a bit compared to the no differentiation case.

UPLOAD DATA THROUGHPUT (AVERAGE)



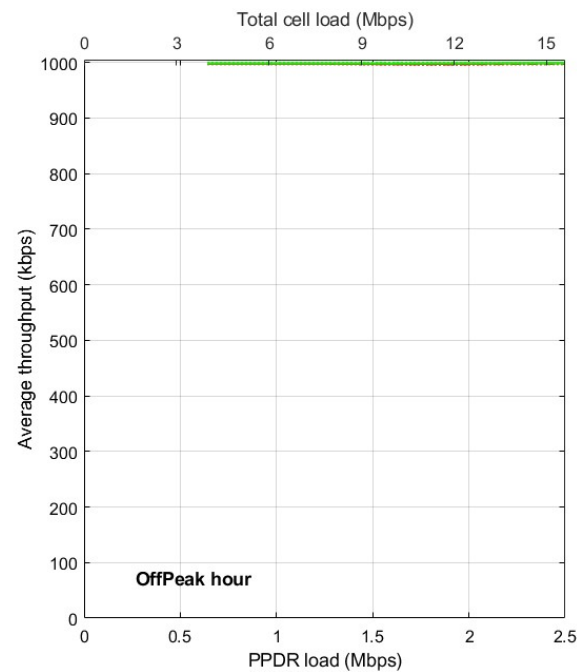
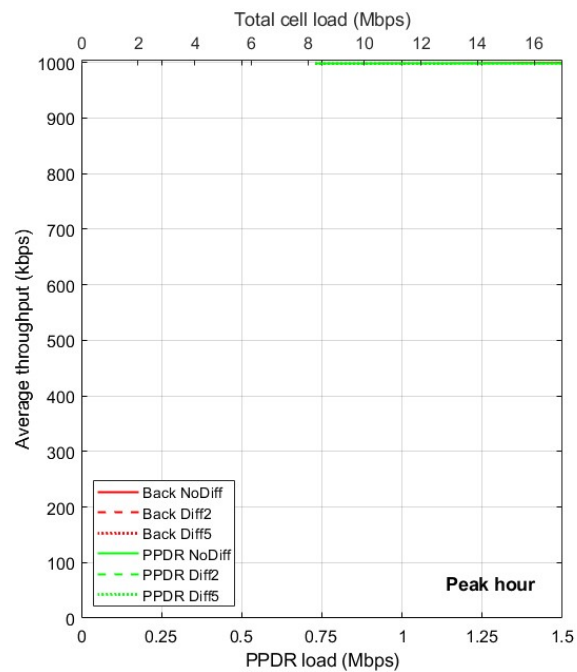
- › PPDR prioritization does not result in difference (i.e. improvement or degradation) in throughput experience.
- › The particular choices we have made for PPDR prioritization in this study results in improvement for PPDR services in terms of blocking rate rather than improvement in throughput.
- › Different operator specific choices can be made in the prioritization policy which can lead to different results (e.g. better throughput instead of lower blocking rate).

UPLOAD VIDEO THROUGHPUT (AVERAGE)



› Similar trend as the upload data traffic performance.

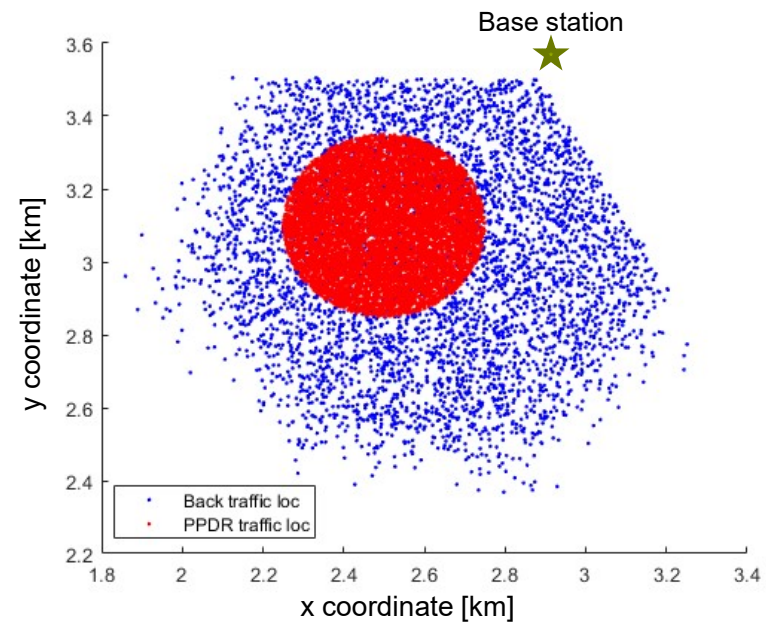
CONVERSATIONAL VIDEO THROUGHPUT (AVERAGE)



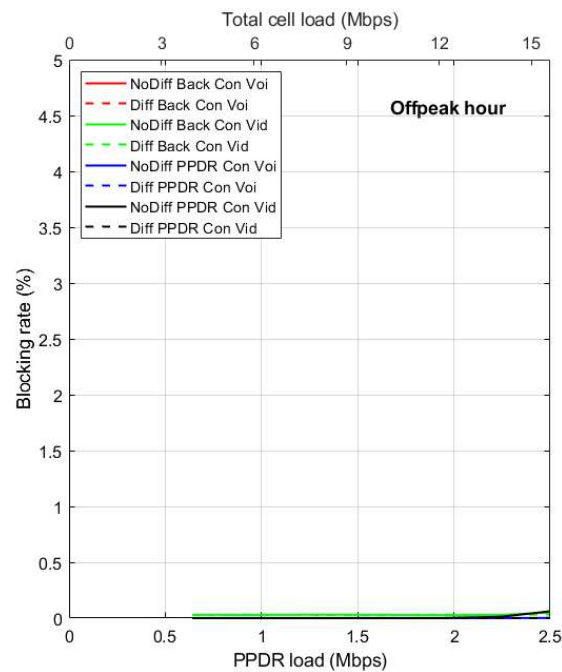
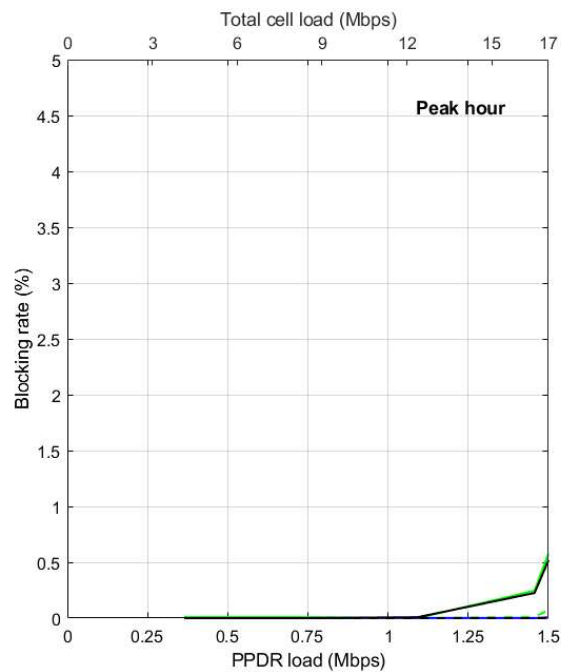
- › Conversational video does not get affected by the increased load.

RURAL HOTSPOT BEST

- › Cell is assumed to fit in a theoretical hexagonal structure
- › Only background traffic locations (i.e. users) are *uniformly distributed* throughout the cell
- › PPDR users are located in a circular hotspot
- › The hotspot is located close to the base station
 - › Thus PPDR users experience favourable radio conditions compared to the background users

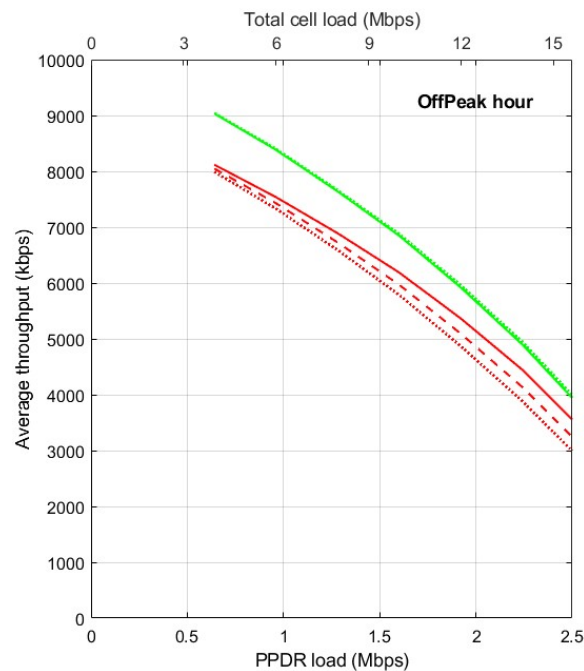
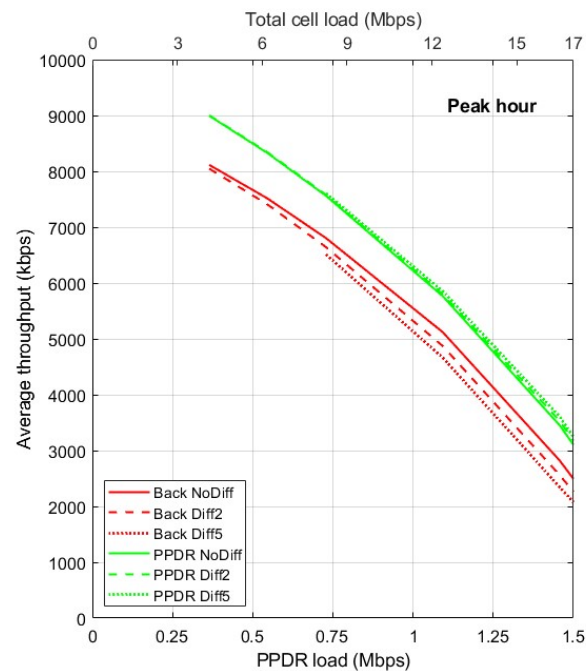


BLOCKING RATE



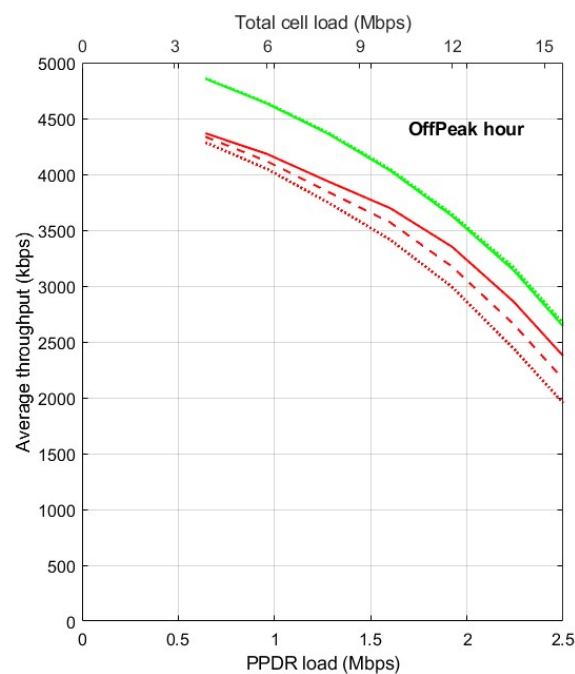
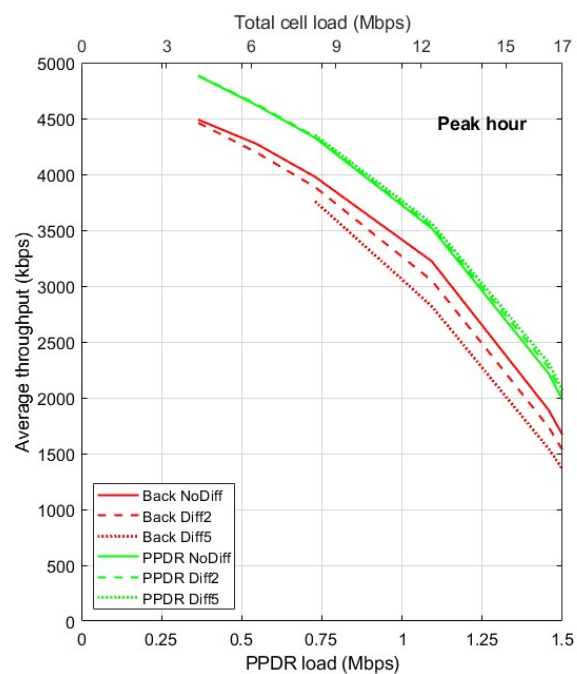
- › Negligible blocking experienced by all services.
- › Consequently performance improvement in terms of blocking rate when applying differentiation, is also minimal.

UPLOAD DATA THROUGHPUT (AVERAGE)



- › Due to the favourable condition (located close to the base station)
 - › PPDR services experience higher throughput than that of the background traffic.
- › Differentiation introduce:
 - › Negligible performance improvement for the PPDR services (note: those are already experiencing high throughput);
 - › Slight performance degradation of background services.

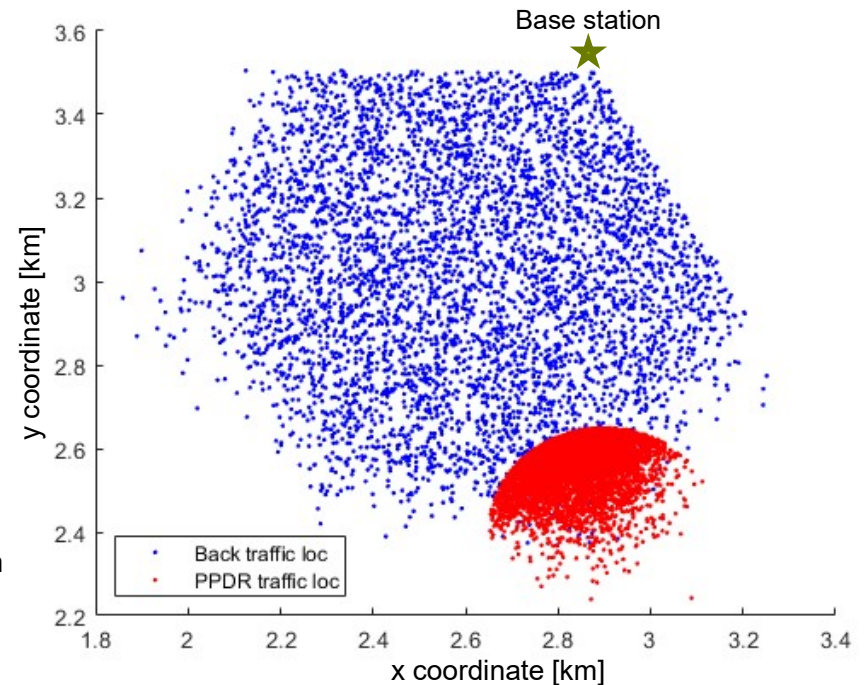
UPLOAD VIDEO THROUGHPUT (AVERAGE)



› Similar trend as the upload data traffic performance.

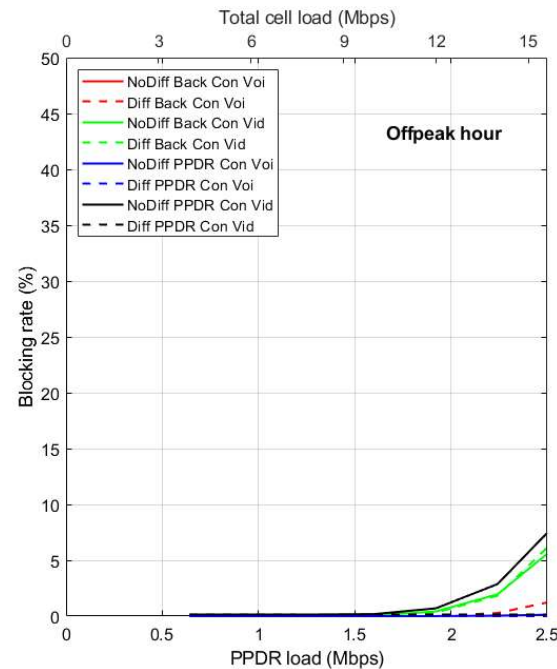
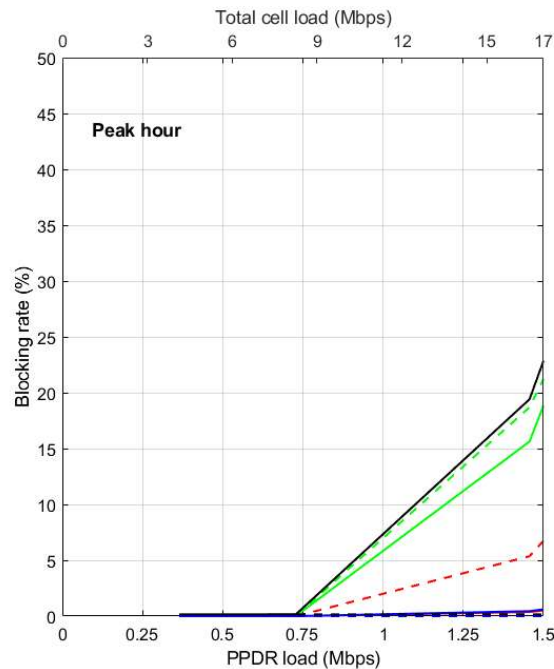
RURAL HOTSPOT WORST

- › Cell is assumed to fit in a theoretical hexagonal structure.
- › Only background traffic locations (i.e. users) are *uniformly distributed* throughout the cell.
- › PPDR users are located in a circular hotspot
- › The hotspot is located on the cell edge
 - › Thus PPDR users experience unfavourable radio condition compared to the background users
 - › Due to this specific location, some of the PPDR users will be served by different cells (depending on their radio condition)
 - › Only the (PPDR) users served by the depicted cell are shown in this figure



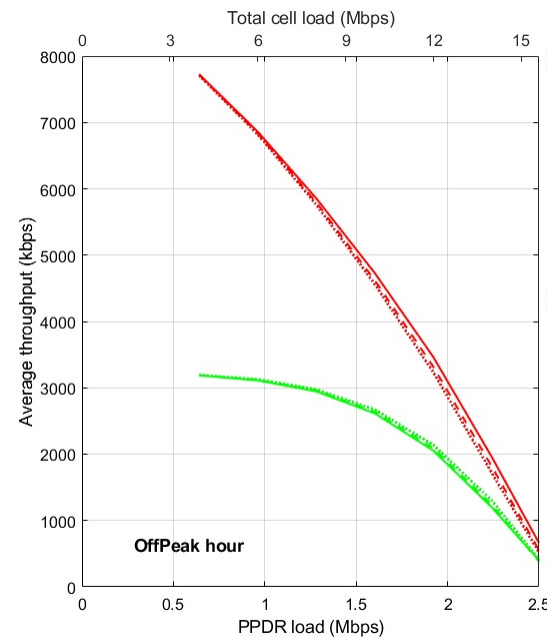
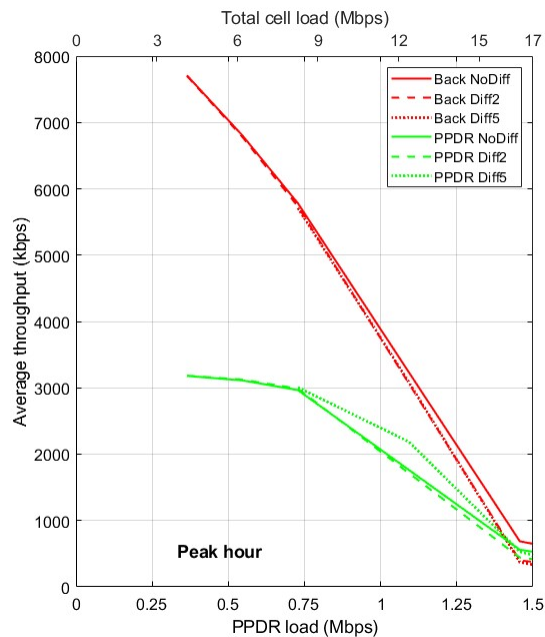
QoS Treatment of PPDR traffic in 3GPP-4G public mobile networks

BLOCKING RATE



- › Higher blocking than those of Rural hotspot best is visible.
 - › Note that the blocking rates are lower than those of the Rural Uniform case because part of these hotspot users (PPDR) are served by different cells.
- › Differentiated case (PPDR traffic prioritization):
 - › PPDR Conversational calls (both voice and video) are not blocked at all;
 - › Background video call blocking remains same as that of the no differentiation case (note such traffic has already experienced significant blocking around the critical load);
 - › Background voice call blocking increases a bit compared to the no differentiation case.

UPLOAD DATA THROUGHPUT (AVERAGE)

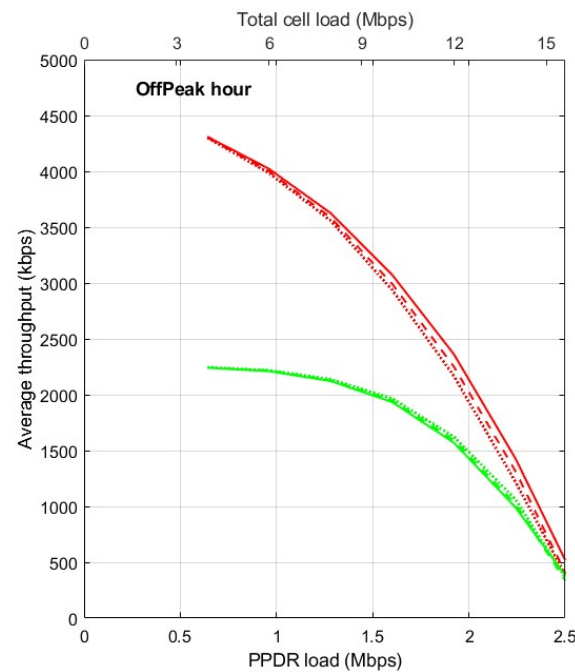
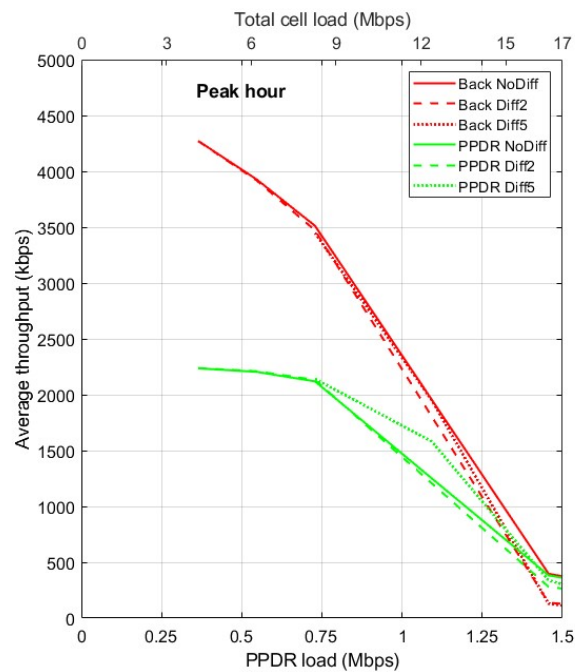


Due to the unfavourable condition (located near the cell edge)

PPDR services experience lower throughput than that of the background traffic

PPDR traffic prioritization results in slight throughput improvement (during peak hours).

UPLOAD VIDEO THROUGHPUT (AVERAGE)



› Similar trend as the upload data traffic performance.

URBAN UNIFORM TRAFFIC LOCATIONS

› Scenario:

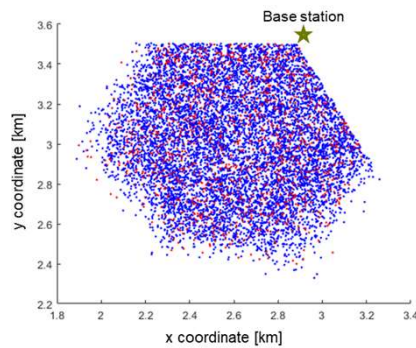
- › Cell is assumed to fit in a theoretical hexagonal structure
- › Both PPDR and Background traffic locations (i.e. users) are *uniformly distributed* throughout the cell
- › The Urban cells have a much smaller ISD and more carriers compared to those in Rural Uniform scenario mentioned on the slide # 27
- › Other than this Urban Uniform scenario has the same deployment consideration as the Rural Uniform scenario

› Results:

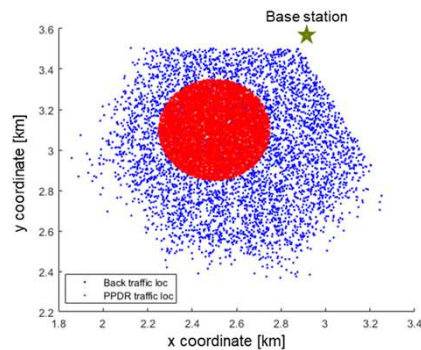
- › Similar trends as the Rural Uniform scenarios
 - › Total cell capacity is much higher thus the cell can handle much higher load
- › For complete results on blocking rate and experience throughput, please check the Annex (slide # 63-68)

ANALYSIS

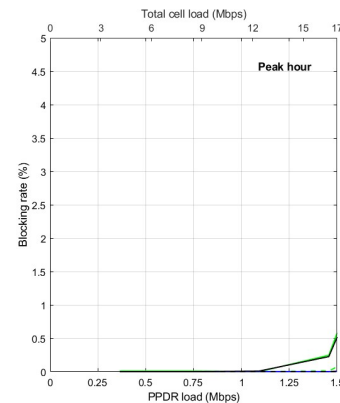
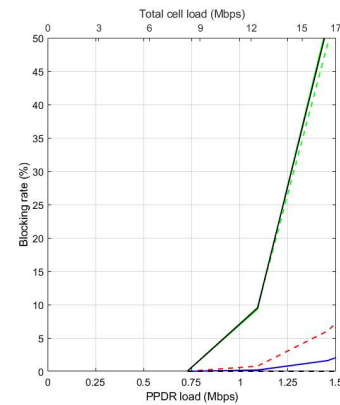
Rural uniform



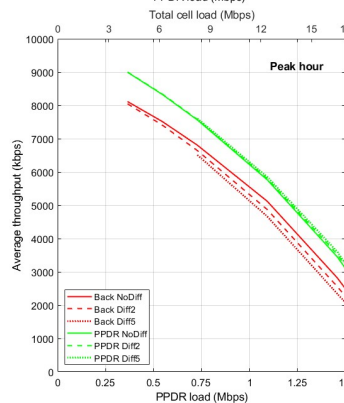
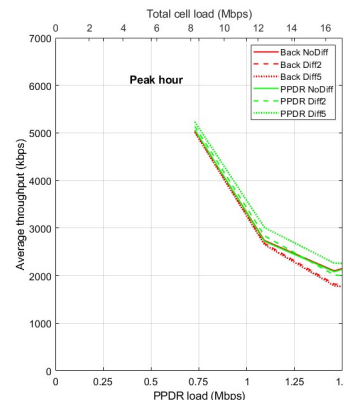
Rural hotspot best



Blocking



Upload data throughput



- › The location of the PPDR users influences the QoS significantly
- › A favourable location results in:
 - › lower blocking compared to that in the case of uniformly distributed users and
 - › better throughput compared to that in the case of uniformly distributed users (differentiation does not give additional benefit here)
- › The opposite will happen if the PPDR hotspot is located at the cell edge
 - › Differentiation will improve the QoS of the PPDR services
 - › through lower blocking and
 - › higher throughput in some cases

CONCLUSIONS

- › Through this work we have illustrated that in 3GPP compatible contemporary networks it is possible to influence and improve the QoS treatment of PPDR traffic against background traffic under congested circumstances.
- › If no differentiation is made between PPDR and background traffic
 - › Both services experience similar performance
 - › A significant amount of the conversational video calls (both background and PPDR) are blocked when cell load becomes too high (double or higher) compared to the usual peak hour load due to an incident
 - › May occur during extreme situations (e.g. natural disaster, national crisis, major incident in remote areas)
- › Differentiated treatment of PPDR traffic (both in admission control and resource scheduling) results in the following
 - › For PPDR services:
 - › Lower blocking rate (almost all the calls are admitted) of PPDR traffic
 - › Even during the congested period (extreme high cell loads)
 - › Slightly higher throughput (or at least similar performance as no differentiation case)
 - › For Background services:
 - › Higher blocking rates (increase trend with the load)
 - › Slightly lower throughput
- › Different approaches (other than the ones considered in this work) could be applied for the prioritization of PPDR traffic over background traffic that may result in different QoS experience (such as higher throughput gain at cost of higher blocking rate).

RECOMMENDATIONS

- › Interactions with a relevant MNO active in the Netherlands would be helpful to validate choices we made regarding priority policies and to identify also relevant alternatives, because we made certain choices for admission control and radio resource scheduling while in practice a particular operator may apply different policies
 - › For example, the admission control policy in this work results almost no blocking in PPDR services
 - › If we would choose a moderate admission control policy, we might have seen improved throughput experience at the cost of somewhat higher blocking of PPDR services.
- › During the final presentation of this study at the Police headquarters in Driebergen on December 20, 2018, the potential usefulness of these insights were recognized although several aspects could be identified which should be looked at in any prolongation of this work in order to increase its practical value. This particularly concerned the inclusion of group calls and some of the statistical assumptions we made for PPDR traffic.
- › In case a prolongation of this work is appreciated by the Ministry of Justice and Security and by the Police, we believe this must be set up such that 1) it improves further our understanding of some of the results of this study as identified in the slides earlier and 2) it improves the practical usefulness of such results to the Dutch PPDR domain. This would at least involve more detailed discussions with the user organisations on scenario and traffic modelling, talks with at least one MNO to discuss and validate policies for prioritization of PPDR traffic and likely some extensions to the current simulation functionality.

REFERENCES

- [1] *Facilitering missie-kritisch mobiel breedband voor het OOV-domein*, TNO report 2017 R11193 (Dutch, separate English management summary available).
- [2] *IMT traffic estimates for the years 2020 to 2030*, ITU-R M.2370-0, pub 2014.
- [3] *Mobile data trends*, Viavi Solutions Inc. White paper, 2016.
- [4] *Ericsson Mobility Report*, Ericsson, June 2018 (ericsson.com/mobility-report).
- [5] *Average call length per mobile voice subscription in Sweden from 2007 to 2017 (in minutes)*
<https://www.statista.com/statistics/654331/average-mobile-call-length-in-sweden/>
- [6] *LEWP-ETSI-FM49 matrix*, Law Enforcement Working Party (EU), Radio Communication Expert Group, 2010-2015.

LIST OF ABBREVIATIONS

3GPP	Third Generation Partnership Project
ARP	Allocation and Retention Priority
DL	Down Link
ISD	Inter Site Distance
ITU	International Telecommunications Union
MNO	Mobile Network Operator
PPDR	Public Protection and Disaster Relief
PRB	Physical Resource Block
QCI	Quality Class Indicator
QoS	Quality of Service
SINR	Signal to Interference plus Noise Ratio

APPENDIX

- › Explanation on 3GPP
- › Detailed modelling aspects
 - › Admission control
 - › Radio resource scheduling
- › Additional results

ADMISSION CONTROL: NOTATION/DEFINITION

- › At any TTI t , denote with
 - › $\rho_{\text{PPDR, CONV}}(t)$ resource claim of PPDR conversational (voice/video) calls
 - › $\rho_{\text{BACK, CONV}}(t)$ resource claim of background conversational (voice/video) calls
 - › where the
 - › resource claim ($\in [0-100\%]$) is the accumulated resource claims over all such calls
 - › user-specific resource claim is defined as the #PRBs it claims per 'frame interval' divided by (available #PRBs / TTI) $\times$ (#TTIs / 'frame interval')
 - › user-specific claimed #PRBs per 'frame interval' is derived from its MCS and the application's minimum codec rate, and truncated by the user-specific maximum number of assignable PRBs, which in turn is derived from the uplink power control scheme

ADMISSION CONTROL SCHEME₀

NO DIFFERENTIATION AMONG PPDR AND BACKGROUND TRAFFIC

- › Consider a user initiating a new **conversational** (voice/video) call at time t
 - › Assume a requested resource claim of ρ_{LOW}
 - › ρ_{LOW} is derived from its MCS, the conversational service type and assumes the lowest codec
- › The call is admitted if and only if
 - › $\rho_{\text{PPDR, CONV}}(t) + \rho_{\text{BACK, CONV}}(t) + \rho_{\text{LOW}} \leq 70\%$
- › An admitted conversational call starts at the highest possible codec rate
 - › *Note:* that it is possible that admission increases the resource claim above 100%; the codec adaptation scheme will respond to that; on its own timescale
- › An **upload** (video/data) call is always admitted

ADMISSION CONTROL SCHEME, PRIORITIZATION OF PPDR TRAFFIC OVER BACKGROUND TRAFFIC

- › Consider a user initiating a new **conversational** (voice/video) call at time t
 - › Assume a requested resource claim of ρ_{LOW}
 - › ρ_{LOW} is derived from its MCS, the conversational service type and assumes the lowest codec
- › The call is admitted if and only if
 - › $\rho_{\text{PPDR, CONV}}(t) + \rho_{\text{BACK, CONV}}(t) + \rho_{\text{LOW}} \leq 70\%$ (background calls)
 - › $\rho_{\text{PPDR, CONV}}(t) + \rho_{\text{LOW}} \leq 100\%$ (PPDR calls)
- › An admitted conversational call starts at the highest possible codec rate
 - › *Note: that it is possible that admission increases the resource claim above 100%; the codec adaptation scheme will respond to that; at its own timescale*
- › An **upload** (video/data) call is always admitted

RADIO RESOURCE SCHEDULING

GENERAL ASPECTS

› Assumptions

- › No multipath fading is considered
- › Signal and MCS are considered constant for a user
- › *Noise* rise: 3dB
- › The scheduler checks this and translates it to PRBs

› Resource calculation:

- › The UL transmit power of the UE (P_{Tx}) depends on the power spectral density
- › $PSD = P_0 + \alpha PL$, Based on P_{max} , we can calculate the # of PRBs allowed in a TTI
- › $SINR = \frac{S}{I+N}$ which translates to a particular MCS and subsequently to the # of bits

RADIO RESOURCE SCHEDULING

GENERAL ASPECTS: CODEC RATE

- › Conversational services use different encoding mechanisms to prepare raw data (e.g. voice, video) to be transmitted over the medium (in this case wireless).
 - › Depending on this encoding, conversational services produce a certain amount of data that needs to be transmitted periodically
- › Codec rate specify the bit rate that needs to be supported for a specific service.
 - › E.g. Cellular voice calls are encoded with Adaptive Multi-Rate (AMR) coding which produces data with a bitrate of 12.2 kbit/s

RADIO RESOURCE SCHEDULING CONVERSATIONAL CALL SPECIFIC (1/2)

- › Based on the codec type used, we also know the packet size and heart bit rate of voice and conversational calls

Service	Packet size	Heart bit
Voice	300 bit	20 ms
Video (1000 kbit/s)	40 kbit	40 ms
Video (750 kbit/s)	30 kbit	
Video (500 kbit/s)	20 kbit	

- › # of PRBs for a call = $\frac{\text{Packet size}}{\text{\# of bits}}$

RADIO RESOURCE SCHEDULING CONVERSATIONAL CALL SPECIFIC (2/2)

- › The scheduling matrix has a dimension of $\left(\# \text{ of Total available PRBs}, \frac{\text{Hert bit rate of the service (in ms)}}{\text{TTI length (i.e.10 ms)}} \right)$
- › Maximum allowed PRBs in the scheduling matrix and the *# of PRBs for a call* will determine the combination in the scheduling matrix
- › Considerations:
 - › $P_{max} = 0.2W$, $P_0 = -80dBm$, $\alpha = 0.8$
- › Additional notes:
 - › It is not explicitly modelled which PRBs in which TTIs are assigned to which call
 - › The aggregate resource claim is assumed to be uniformly distributed over time
 - › A user-specific maximum #PRBs is applied, derived from transmit power calculations

RADIO RESOURCE SCHEDULING SCHEME₀ NO DIFFERENTIATION AMONG PPDR AND BACKGROUND TRAFFIC

› **Conversational** (voice/video) calls:

- › are assigned the resources they claim, based on the current codec
- › If the aggregated resource claim based on current codec exceeds 100%, resource assignments need to be reduced
- › If reductions are needed, we first check whether it suffices to only reduce conversational video calls down to at worst their minimum codec rate, trying to leave voice calls (operating at a fixed codec rate) unaffected
- › If that does not work, then both voice and conversational video calls are fairly reduced with respect to their fixed and minimum codec rates, respectively

› **Upload** (video/data) calls

- › In each TTI, the remaining resources are shared in an egalitarian fashion among all upload calls

RADIO RESOURCE SCHEDULING SCHEME₁ PRIORITIZATION OF PPDR TRAFFIC OVER BACKGROUND TRAFFIC

› *Conversational (voice/video) calls*

- › PPDR calls are assigned the resources they claim, based on the current codec
- › If the aggregated PPDR resource claim exceeds 100%, the resource assignments of the PPDR calls are reduced as under SCHEME₀
- › Idem for background calls, but considering the remaining resources, after dealing with the PPDR calls
- › Note that this implies that PPDR calls have priority over background calls in claiming resources at times of congestion

› *Upload (video/data) calls*

- › In each TTI, the remaining resources are shared in an differentiated fashion among all upload calls, applying sharing weights $\gamma_{\text{PPDR}} \geq \gamma_{\text{BACK}} = 1$, respectively

RADIO RESOURCE SCHEDULING

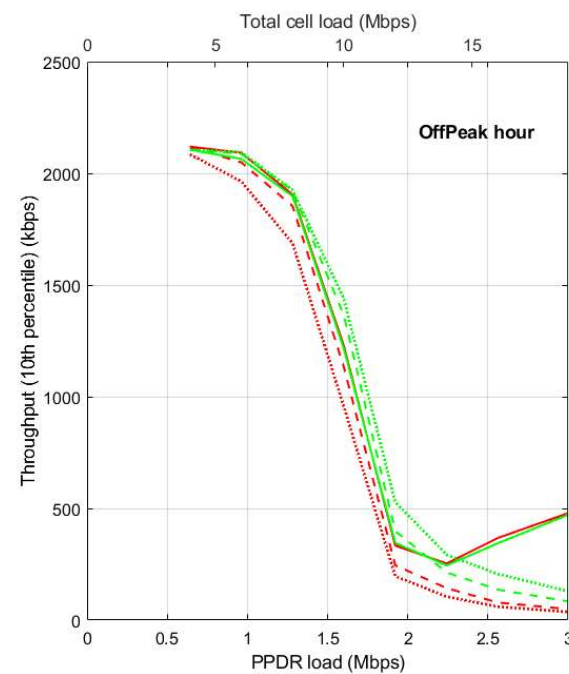
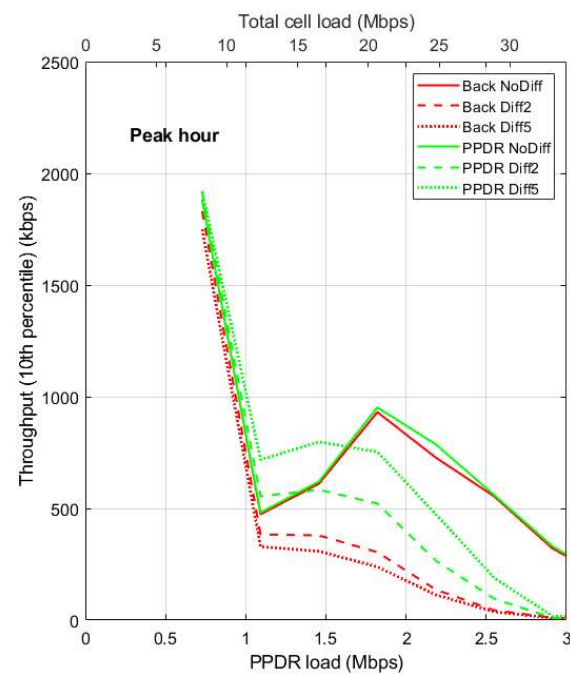
CODEC ADAPTATION FOR CONVERSATIONAL VIDEO CALLS

- › As voice calls are assumed to have a fixed codec rate, this is only about conversational video calls
- › Each conversational video call has a fixed heartbeat, h.l. at a regular interval of 0.040 seconds, at which a change in codec is considered
- › At such an adaptation instant t , denote with $R_t(u)$ the average bit rate experienced by user u over the past such interval, and with $\underline{R}_t(u)$ the bit rate corresponding to the used codec
- › If $R_t(u) / \underline{R}_t(u) > \alpha_{UP}$ then the codec level is increased by one step (if possible)
- › Else if $R_t(u) / \underline{R}_t(u) > \alpha_{KEEP}$ then the codec level is kept the same
- › Else the codec level is reduced by one step
- › If the codec level is reduced below the lowest available level, the call is dropped
- › Otherwise, the newly selected codec level is applied for the duration of the upcoming interval

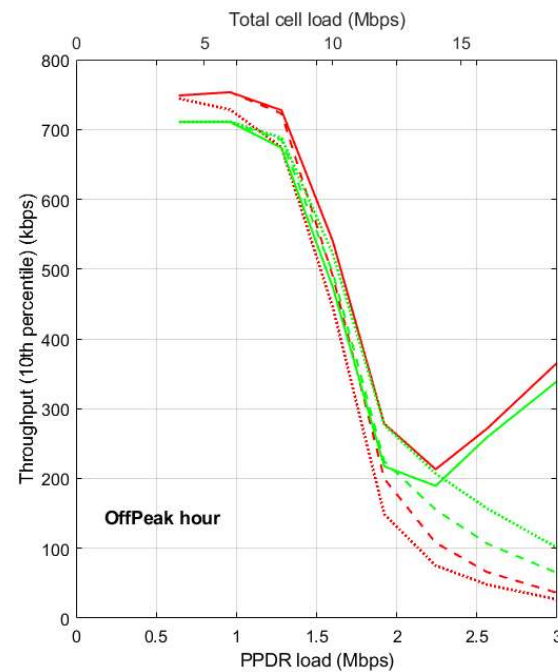
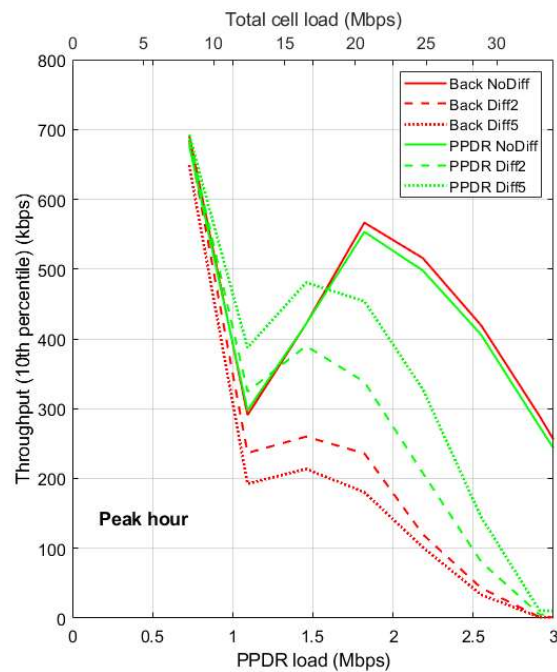
RADIO RESOURCE SCHEDULING CODEC ADAPTATION (VISUALISATION)



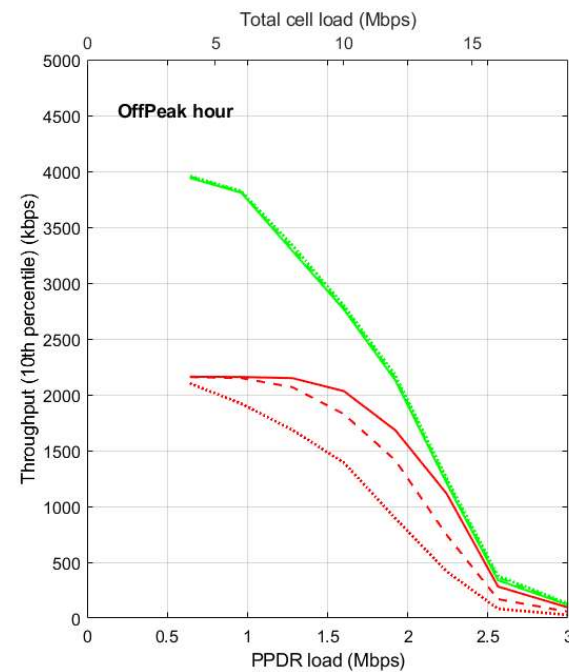
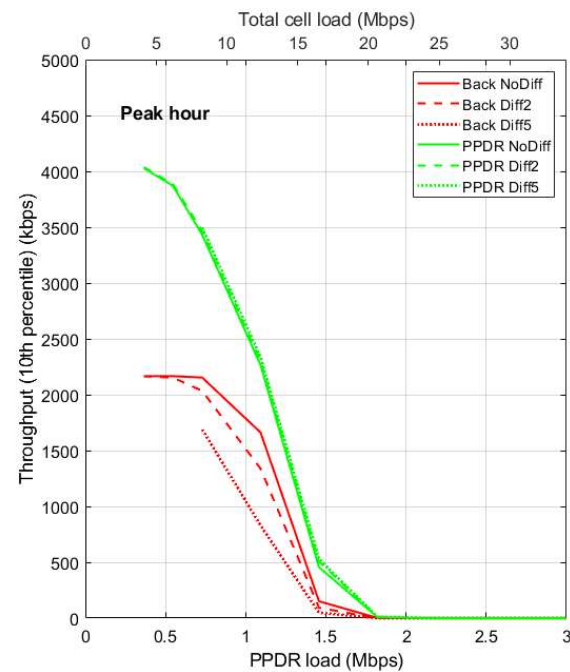
UPLOAD DATA THROUGHPUT (10TH PERCENTILE)



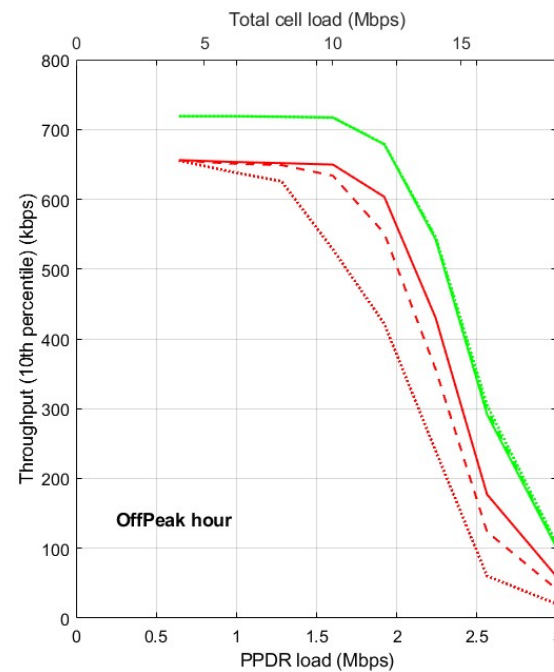
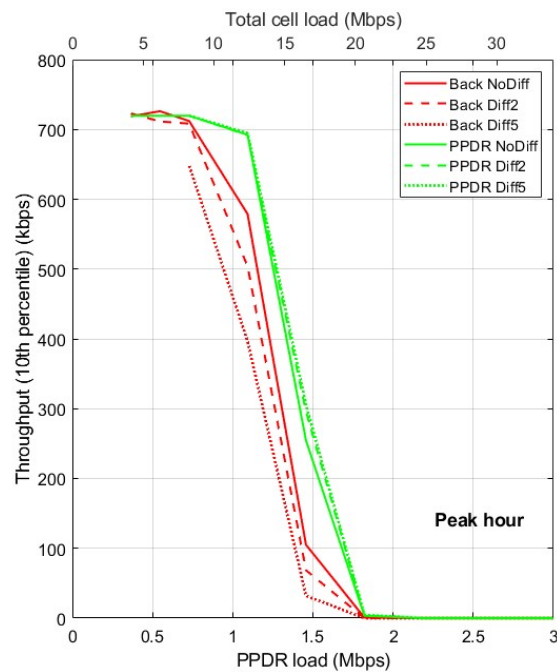
UPLOAD VIDEO THROUGHPUT (10TH PERCENTILE)



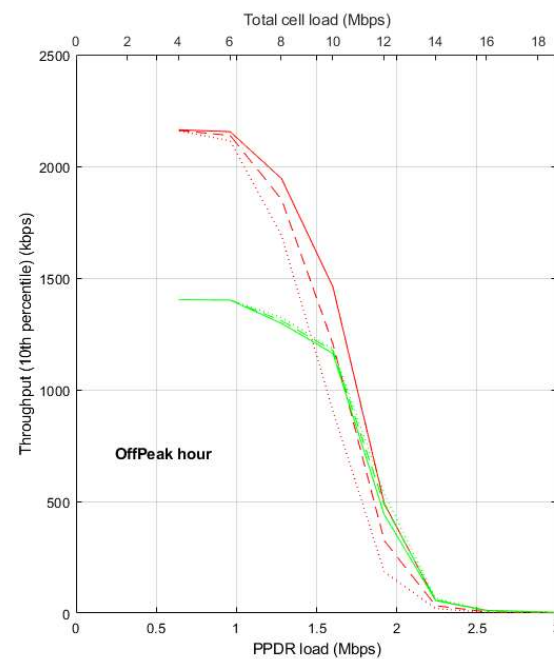
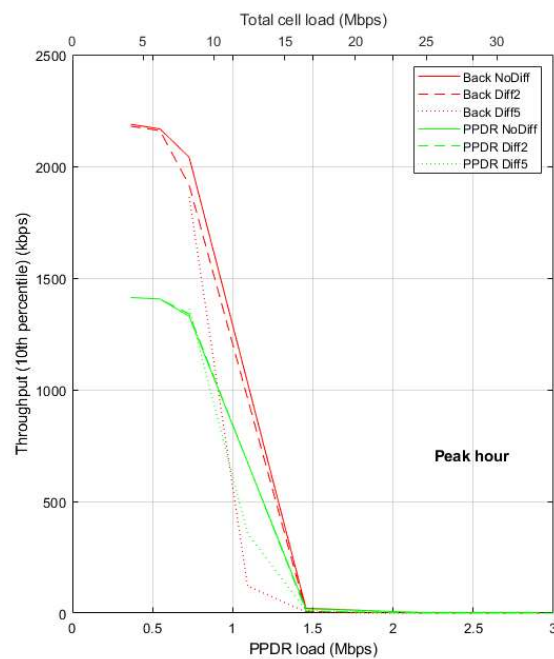
UPLOAD DATA THROUGHPUT (10TH PERCENTILE)



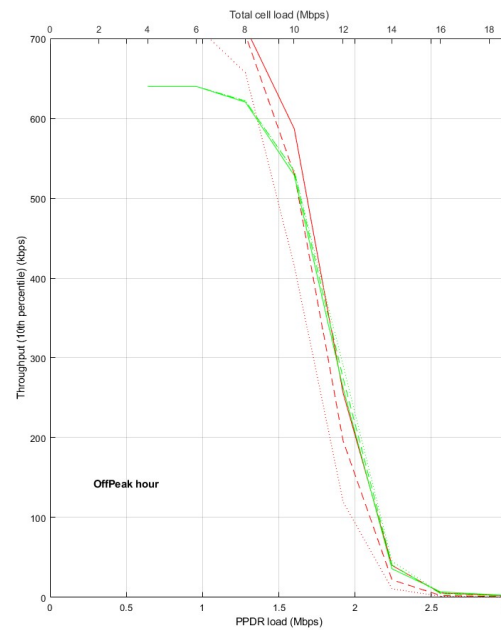
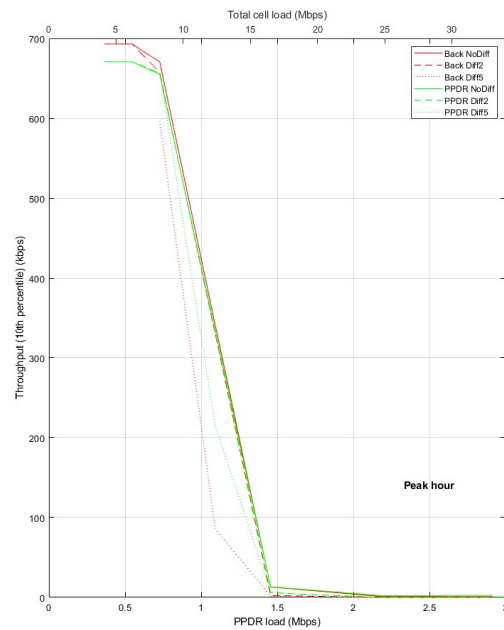
UPLOAD VIDEO THROUGHPUT (10TH PERCENTILE)



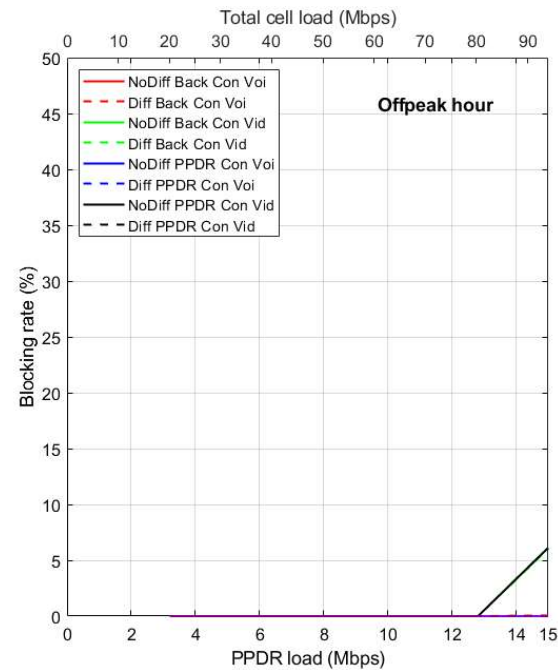
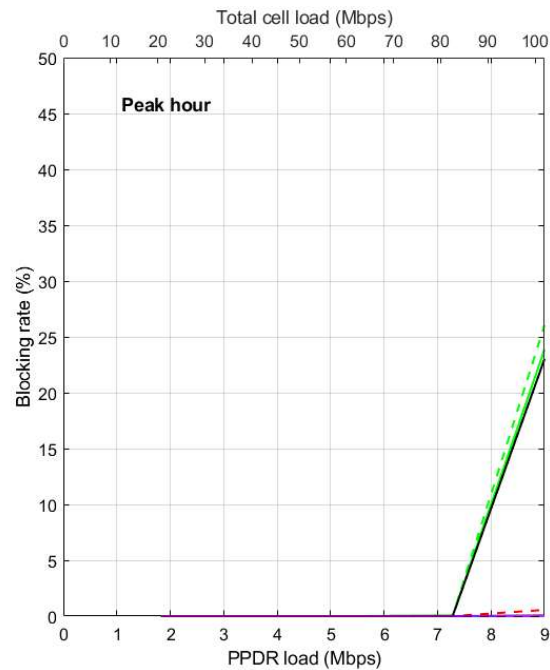
UPLOAD DATA THROUGHPUT (10TH PERCENTILE)



UPLOAD VIDEO THROUGHPUT (10TH PERCENTILE)

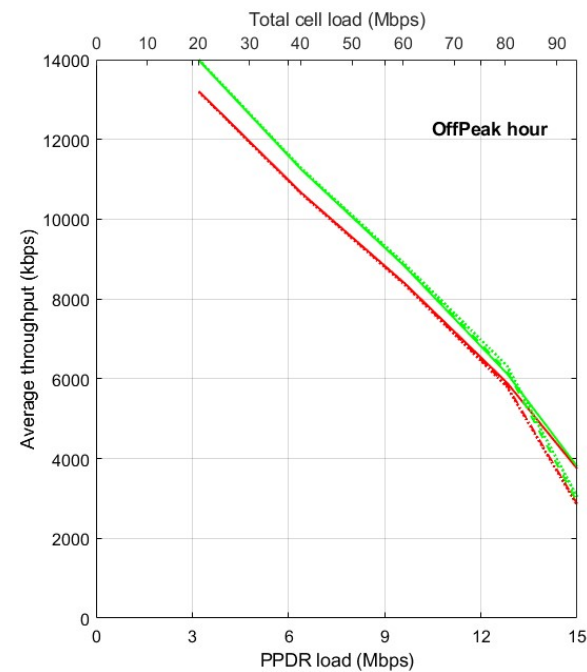
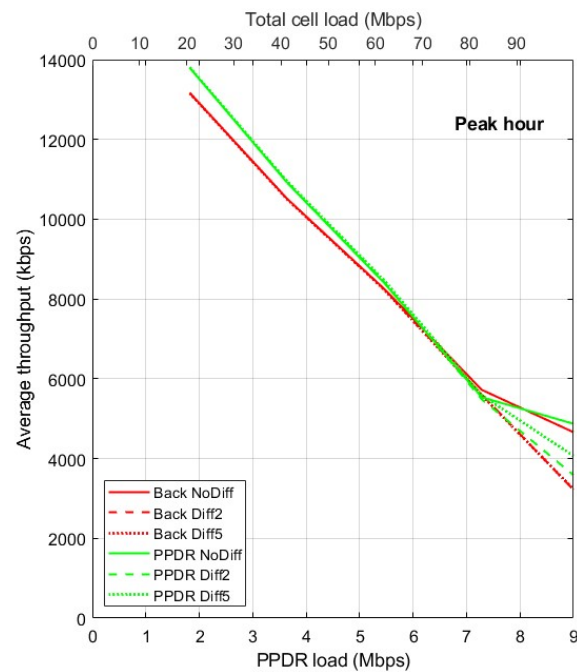


BLOCKING RATE

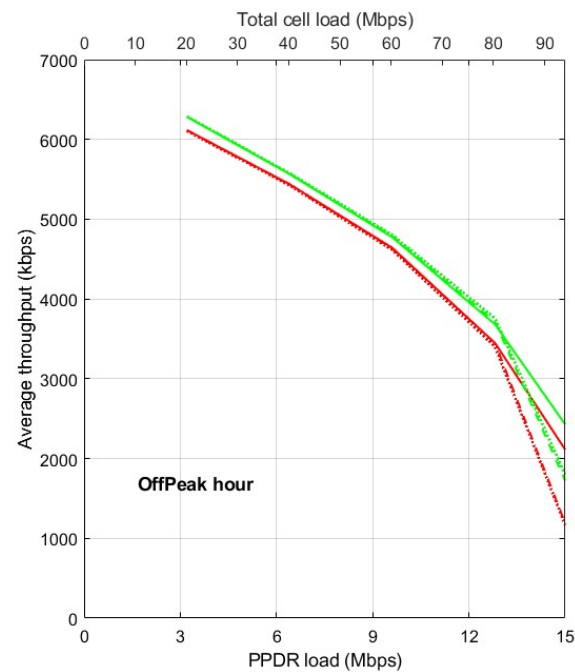
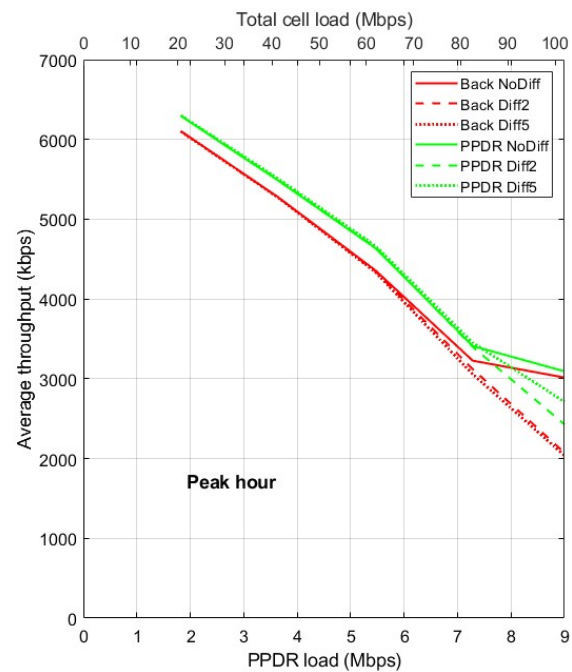


› PPDR Conversational calls (both voice and video) are not blocked at all when priority has been applied.

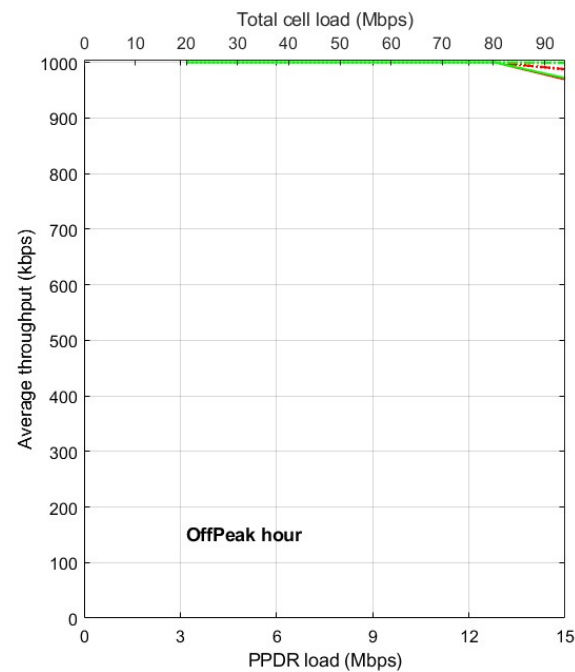
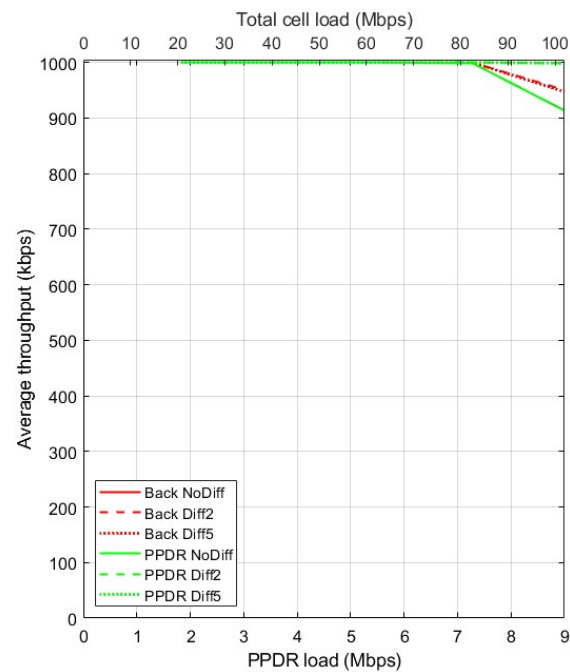
UPLOAD DATA THROUGHPUT (AVERAGE)



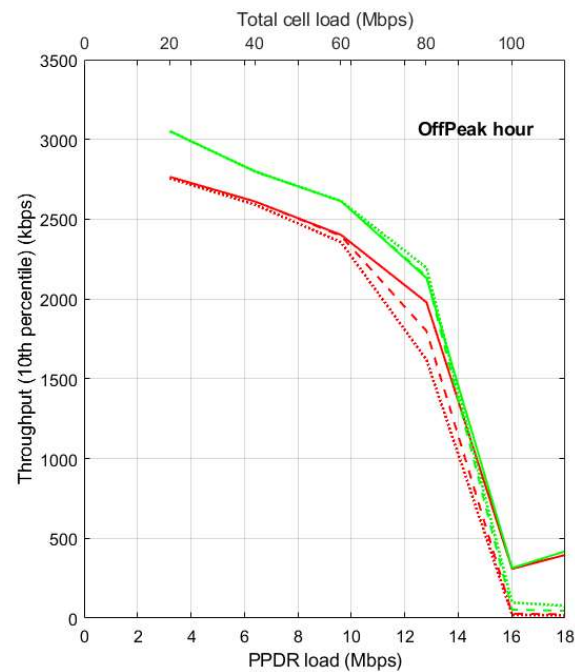
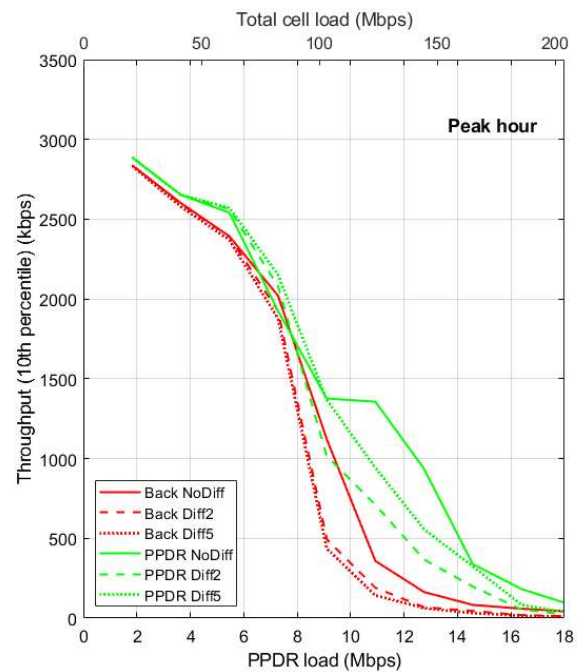
UPLOAD VIDEO THROUGHPUT (AVERAGE)



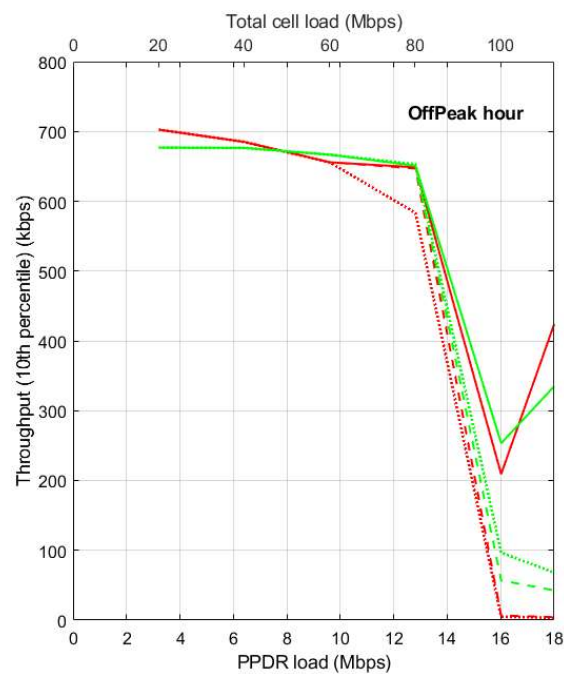
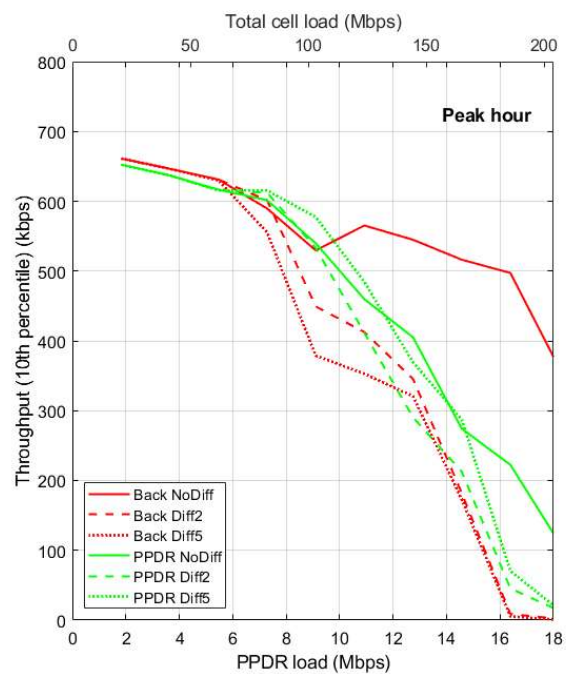
CONVERSATIONAL VIDEO THROUGHPUT (AVERAGE)

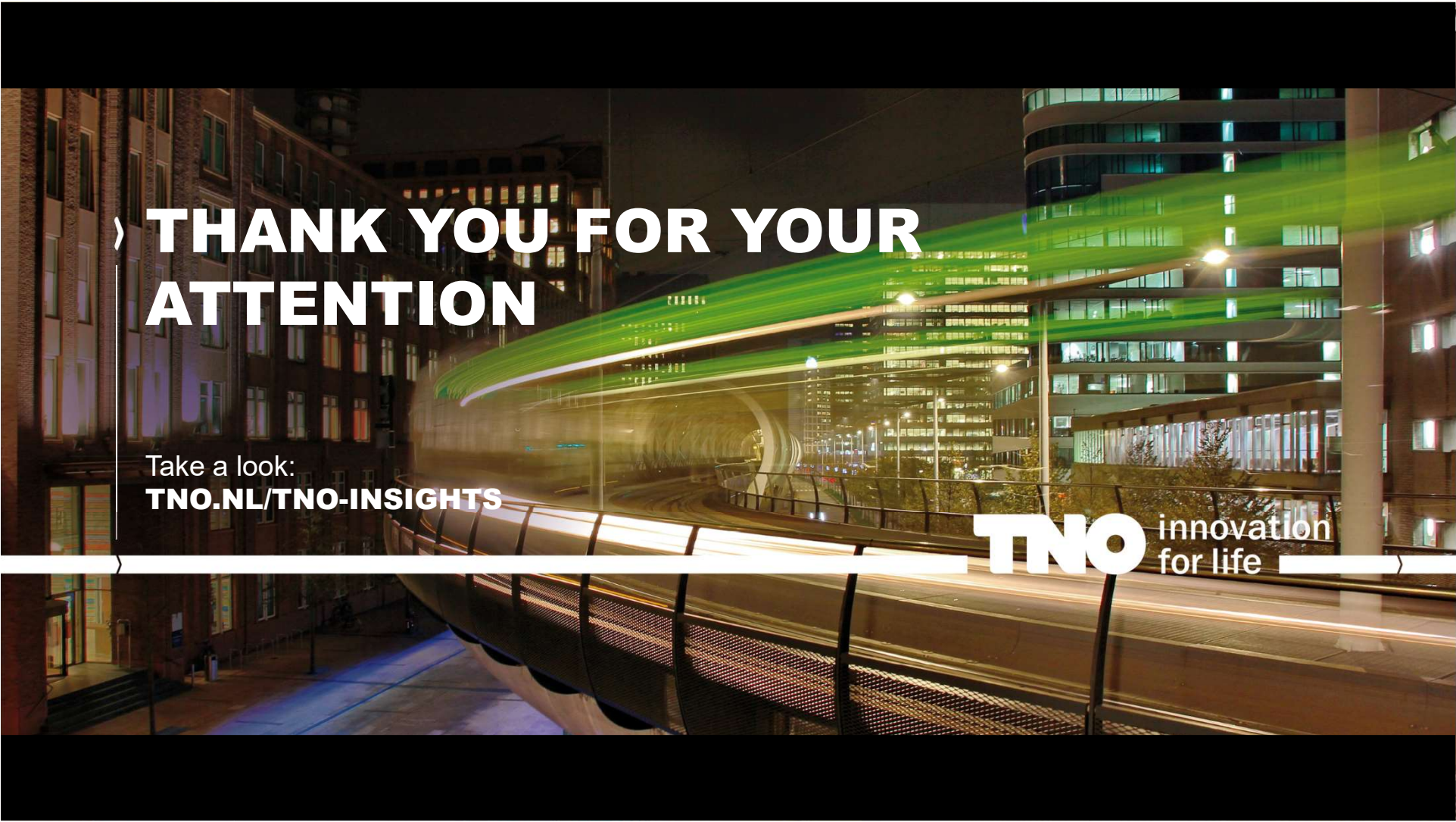


UPLOAD DATA THROUGHPUT (10TH PERCENTILE)



UPLOAD VIDEO THROUGHPUT (10TH PERCENTILE)



A nighttime photograph of a city street. On the left is a brick building with many lit windows. On the right is a modern building with a curved facade and lit windows. In the foreground, a curved metal railing runs across the frame. Long, horizontal light trails in green and yellow are visible, suggesting motion from a train or tram. The overall scene is illuminated by city lights.

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