OCTANE: A Joint Computation Offloading and Resource Allocation Scheme for MEC Assisted 5G NR Vehicular Networks

Veerendra Kumar Gautam, Chinmay Tompe, Bheemarjuna Reddy Tamma and Antony Franklin A.

Networked **W**ireless **S**ystems **(NeWS)** Lab
Department of Computer Science & Engineering
Indian Institute of Technology, Hyderabad

భారతీయ సాంకేతిక విజ్ఞాన సంస్థ హైదరాబాద్
भारतीय प्रौद्योगिकी संस्थान हैदराबाद
Indian Institute of Technology Hyderabad

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Introduction to V2X

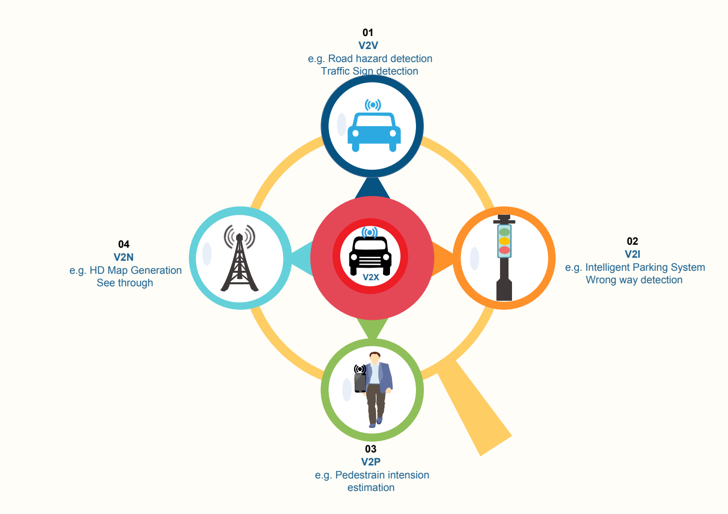


FIGURE 1: Types Of V2X Communication Modes

High Definition Map (Motivation Example)

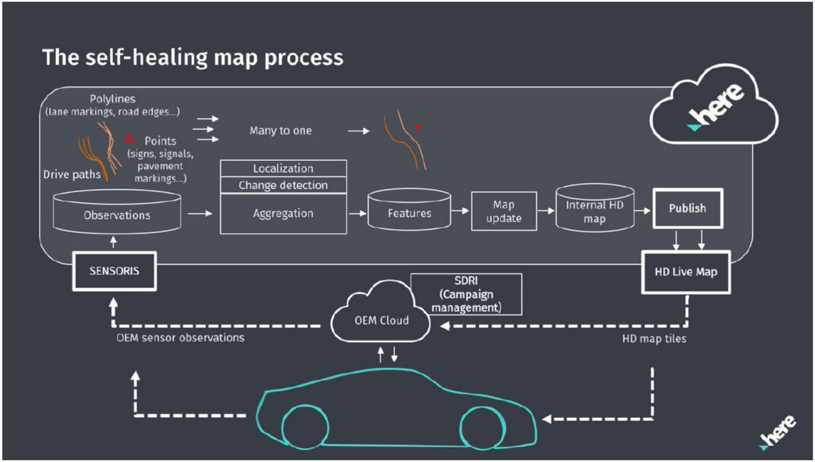


FIGURE 2: HD MAP [1]

[1] Reference: "https://www.here.com/sites/g/files/odxslz166/files/2019-01/THE FUTURE OF MAPS.pdf"

System Model

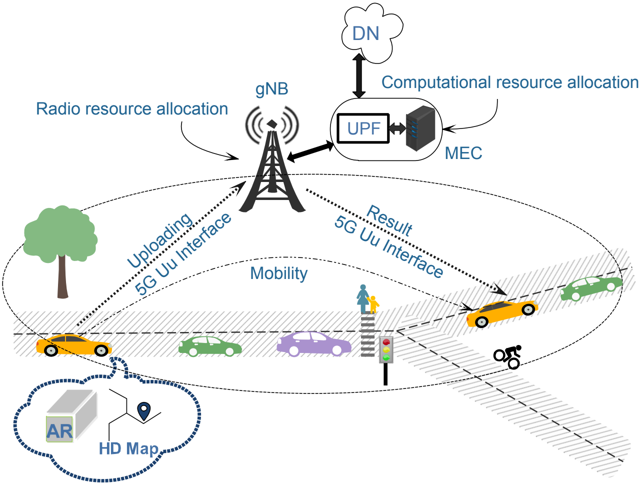


FIGURE 3: System Model

Task Offloading Application

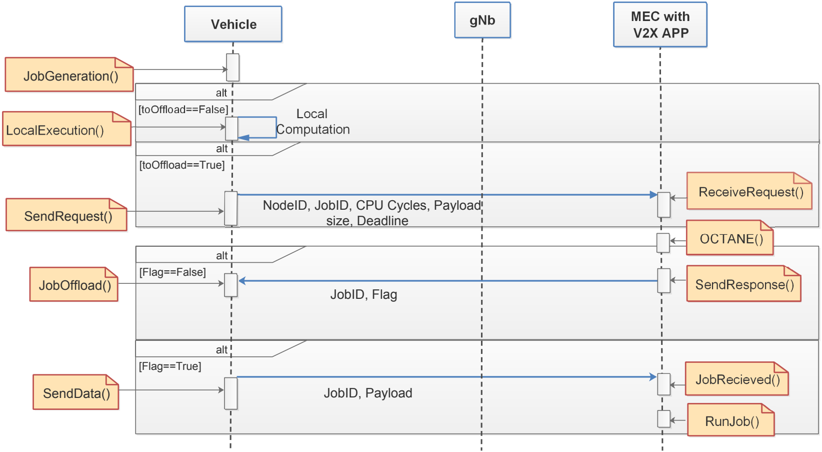


FIGURE 4: Sequence Diagram of Task Offloading Application.

Notations Used

Symbol	Description
V	Set of vehicles
K	Set of jobs
K'	Set of jobs offloaded to MEC
$W_{v,k}$	Job tuple
$\alpha_{v,k}^{in}$	Input size of the job
$\beta_{v,k}^{cpu}$	CPU cycles required for the job
$\gamma_{v,k}^{delay}$	Deadline of the job
$T_{v,k}^{local}$	Local computational delay for the job
$T_{v,k}^{mec}$	MEC computational delay for the job
$T_{v,k}^{NR}$	5G NR Transmission Delay
f_v^{local}	Vehicle's processing capacity
$Fmax$	MEC server's processing capacity
$x_{v,k}$	Number of RBs required for the job
$y_{v,k}$	Number of CPU cycles required for the job
rbg_{th}	Resource Block Threshold for the job
job_{th}	Job threshold per vehicle per second
N_{total}^{RB}	Total number of RBs per second
$t_{\text{slot}}^{\text{NR}}$	Slot duration in 5G NR
$\phi_{v,k}$	Vehicle side binary variable for offloading
$\eta_{v,k}$	MEC side binary variable for offloading

MEC Side Formulation

- The objective is to maximize the number of jobs admitted by the MEC server by Eqn. $P_{\mathbf{MEC}}$ s.t. constraints given in Eqns. $\mathrm{C_{MEC}}1$, $\mathrm{C_{MEC}}2$, $\mathrm{C_{MEC}}3$, $\mathrm{C_{MEC}}4$.

$$P_{\mathbf{MEC}}: \quad \max \sum_{v=1}^{|V|} \sum_{k=1}^{|K'|} \eta_{v,k}$$

- The constraint $\mathrm{C_{MEC}}1$ ensures that the total radio resources required by the offloading jobs should not exceed maximum value N^{RB}_{total} of the 5G NR base station.

$$\mathrm{C_{MEC}}1: \quad \sum_{v=1}^{|V|} \sum_{k=1}^{|K'|} x_{v,k} \times \eta_{v,k} \leq N^{RB}_{total}, \forall v \in V, \forall k \in K'$$

- $\mathrm{C_{MEC}}2$ stands for job threshold per vehicle.

$$\mathrm{C_{MEC}}2: \quad \sum_{k=1}^{|K'|} \eta_{i,j} \leq job_{th}, \forall i \in \mathcal{V}$$

MEC Side Formulation

- $C_{MEC}3$ ensures that total computational resources of the jobs should not exceed maximum CPU capacity of MEC, F_{max}.

$$C_{MEC}3: \quad \sum_{v=1}^{|V|}\sum_{k=1}^{|K'|} y_{v,k} \times \eta_{v,k} \leq F_{max}, \forall v \in V, \forall k \in K'$$

- $C_{MEC}4$ states that transmission delay and computational delay should not exceed job's deadline.

$$C_{MEC}4: \quad T_{v,k}^{NR} + T_{v,k}^{mec} \leq \gamma_{v,k}^{delay}, \forall v \in V, \forall k \in K'$$

- $C_{MEC}5$ indicates offloading decision is a binary variable.

$$C_{MEC}5: \quad \eta_{v,k} \in \{0,1\}, \forall v \in V, \forall k \in K'$$

Mobility-Aware Multi-User Offloading Optimization for Edge Computing.[1]

Optimal Approach and Objective

- Non-linear Integer Programming (NLIP)
- Objective is to maximize the QoS and minimize energy

Proposed Algorithm

- Heuristic Mobility-Aware Offloading Algorithm (HMAOA). It has a complexity of $\mathcal{O}(N^3 \times (F_0/step))$ where F_0 is the cpu frequency of MEC server and step is a time interval.

Tools

- Matlab R2018b

Performance parameters

- Different Number of Vehicles, Running Time, Varying Velocity

Not Considered

- 5G New Radio Features

[1] Reference: W. Zhan, C. Luo, G. Min, C. Wang, Q. Zhu and H. Duan, "Mobility-Aware Multi-User Offloading Optimization for Mobile Edge Computing," in IEEE Transactions on Vehicular Technology, vol. 69, no. 3, pp. 3341-3356.

Proposed Schemes

OCTANE

- We propose an online heuristic for joint computational offloading and resource allocation named OCTANE to solve the $P_{\mathbf{MEC}}$ problem in real-time.
- OCTANE is a $\mathcal{O}(K' \log K')$ complexity iterative solution, which is put forward to solve the offloading decision problem by considering deadline, radio, and computational resource requirements of the jobs of the vehicles.

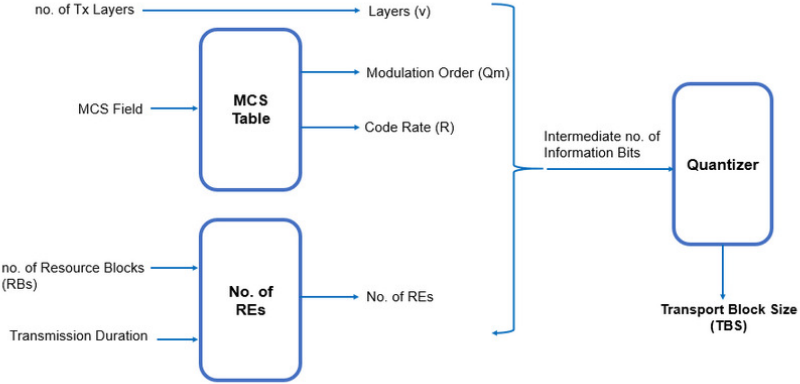
Transport Block Size-based strategy

- To provide fairness among vehicles while job offloading, a Transport Block Size-based strategy is proposed for the MAC layer which runs in accordance with the Maximum Rate (MR) scheduler while allocating TDMA symbols to the vehicles in the Uplink.

ALGORITHM 1: OCTANE

```
inputs  : V, K'
output  : Job Offloading Decision
K^sort ← Sort(K', s.t. γ^delay_{v,k} < γ^delay_{v,(k+1)})
forall v ∈ V do
    if mcs_v ≥ mcs_th then
        D^v_max ← MaxDataTransferPerVehicle(mcs_v) /* Calculate Data Transfer per vehicle */
    end
end
forall k ∈ K^sort do
    T_delay ← TotalDelayPerJob(W_{v,k}, rb_th)
    if k ≤ job^v_th & T_delay ≤ γ^delay_{v,k} then
        if (F_max − β^cpu_{v,k}) ≥ 0 & (D^v_max − α^in_{v,k}) ≥ 0 then
            OffloadJob(1)           /* request offloading */
        else
            OffloadJob(0)           /* reject job */
        end
    end
end
end
```

Transport Block Size in 5G NR



- No. of Layers (v)
- Modulation Order (Qm)
- Coding Rate (R)
- No. of Physical Resource Block (PRB)
- Transmission Duration

Transport Block Size Strategy

ALGORITHM 2: **TBS Strategy**

Input : V
Output : TDMA Symbol Allocation for Vehicles
$TBS_{max} = \texttt{GetMaxTBSsize}(28)$
forall $v \in V$ **do**
  $TBS_v = \texttt{GetTBSsize}(mcs_v)$ /* Calculating Maximum TBS for highest MCS value */
  if $TBS_v \leq TBS_{max}/2$ & $TBS_v > TBS_{max}/3$ **then**
    $SymPerSlot_v = 2$ /* Group 1 */
  end
  if $TBS_v > TBS_{max}/2$ **then**
    $SymPerSlot_v = 1$ /* Group 2 */
  end
  if $TBS_v \leq TBS_{max}/3$ **then**
    $SymPerSlot_v = 1$ /* Group 3 */
  end
end

Simulation Parameters

Parameter	Value
Scenario	Urban Macro Cell
Number Of Vehicles $\|V\|$	10-30
Mobility Model	Krauss
Average Vehicle Velocity (V_{vel})	20-80 kmph
5G NR Base Station/Vehicle TX power	46/10 dBm
5G NR Base Station antenna pattern	Canadian dataset
5G NR Base Station antenna tilt	15°
5G NR Base Station/Vehicle antenna height	25 m / 1.5 m
Carrier Frequency	6 GHz
Channel Model	3GPP, LoS
Channel Condition	Line-Of-Sight
Channel Bandwidth	20 MHz
5G NR Numerology (μ)	1
CPU Clock Frequency Of MEC server ($Fmax$)	80 GHz
Vehicle's CPU Clock Frequency (f_v^{local})	2 GHz
Number of Jobs per Vehicle (K)	[1,2]
Input Size of the job ($\alpha_{v,k}^{in}$)	Mean: 5 KB
	Variance: 10 KB
	Bound: 4 KB
CPU cycles required per job ($\beta_{v,k}^{cpu}$)	[4,140] Mcycles
Deadline of job ($\gamma_{v,k}^{delay}$)	[100,150] msec
Resource Block Threshold per Job (rbg_{th})	1000 RB
Job Threshold per Vehicle per second (job_{th}^{v})	12
Maximum data transfer per vehicle (t_d)	100 msec

Performance Results

Performance Metrics

Offloading Success Rate (OSR)

- OSR is calculated at MEC server for different schemes in a vehicular scenario. Success is accomplished when job is offloaded to the MEC server and completed within its deadline. If a vehicle decides to run a job locally, it is not counted as failure or success.

$$OSR = \left[\frac{NumberOfJobsDone}{TotalNumberOfRequestsReceivedByMECServer} \right] \times 100 \quad (1)$$

Offloading Rate (OR) and Rejection Rate

- OR is the ratio of the number of jobs offloaded to the MEC server to the total number of Jobs offloading requests received by the MEC server. The difference in OSR and OR is derived from the jobs which are offloaded but did not get successfully executed within their deadlines by the MEC server.

$$OR = \left[\frac{NumberOfJobsOffloaded}{TotalNumberOfRequestsReceivedByMECServer} \right] \times 100$$

$$RejectionRate = \left[\frac{NumberOfJobsRejected}{TotalNumberOfRequestsReceivedByMECServer} \right] \times 100$$

Jain Fairness Index (JFI)

$$JFI = \frac{\left(\sum_{i=1}^{n} x_i\right)^2}{n\sum_{i=1}^{n} x_i^2} \tag{2}$$

- In Eqn. (2); x is Offloading Success Rate of i_{th} vehicle and n is the number of vehicle.

Performance Results

For Different Number Of Vehicles

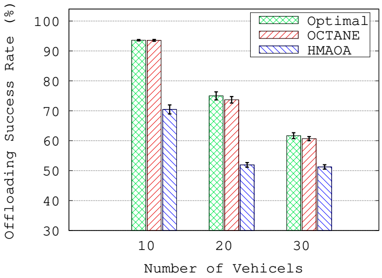


FIGURE 5: OSR Vs numbers of vehicles with $V_{vel} = 60kmph$.

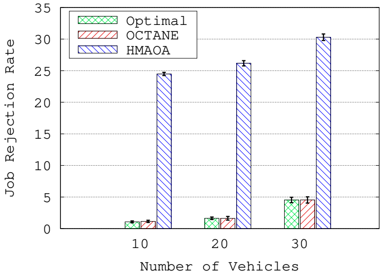


FIGURE 6: Rejection Rate Vs numbers of vehicles with $V_{vel} = 60kmph$.

Observations

- As we increase the number of vehicles, Offloading Success Rate (OSR) decreases.
- OCTANE is close to Optimal value and better than HMAOA .
- Rejection Rate of OCTANE is less than HMAOA and close to optimal.

Performance Results

For Different Velocities of Vehicles

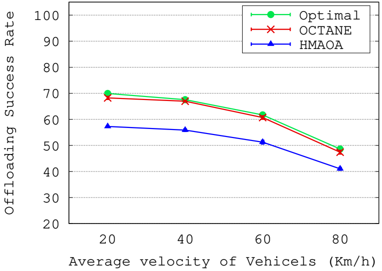


FIGURE 7: OSR Vs velocity of vehicles for $|V| = 30$.

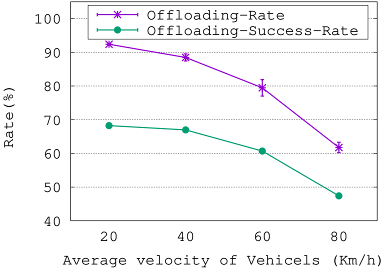


FIGURE 8: OCTANE OSR and OR Vs velocity of vehicles for $|V| = 30$.

Observations

- As we increase the average velocity of vehicles OSR degrades. OCTANE performs better than HMAOA for different velocities.
- OSR and OR degrade as we increase average velocity of vehicles.

Packet Delivery Ratio and Jain Fairness Index

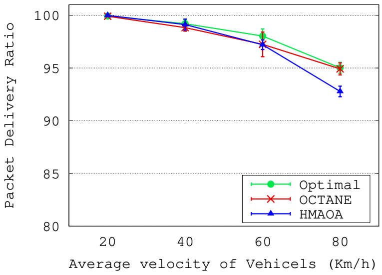


FIGURE 9: PDR Vs velocity of vehicles for $|V| = 30$.

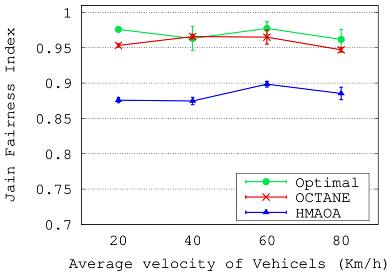


FIGURE 10: JFI Vs velocity of vehicles for $|V| = 30$.

Observations

- PDR decreases as we increase the average velocity of vehicles.
- Jain Fairness Index for OCTANE is better than that of HMAOA.

Conclusions

- We studied the joint job offloading decision, radio resource allocation, and computational resource allocation problem for latency-sensitive vehicular applications in 5G NR based MEC system.
- We proposed OCTANE, which selects jobs for offloading by jointly considering deadlines, computational and communication delays of the jobs.
- To provide fairness among vehicles, we proposed a TBS-based strategy for allocation of TDMA symbols in 5G uplink.
- We have used an HD-map application as a use case to study the effectiveness of OCTANE and performed NS-3 simulations for HD-map application in a highway scenario.
- OCTANE outperformed a state-of-art algorithm in terms of offloading success rate and other metrics.
- As future work, we are working to see the effect of different numerology.

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Email: cs18resch01003@iith.ac.in

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