

Open-Source Prototyping of 5G Wireless Systems for Smart Ag, Autonomous Vehicles and Beyond

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Team Members:

Hye-Sung Moon

Theodore Miller

Anthony Benson

Khanh Luu

Jared Gorton

Jaime Zetina

Adviser & Client:

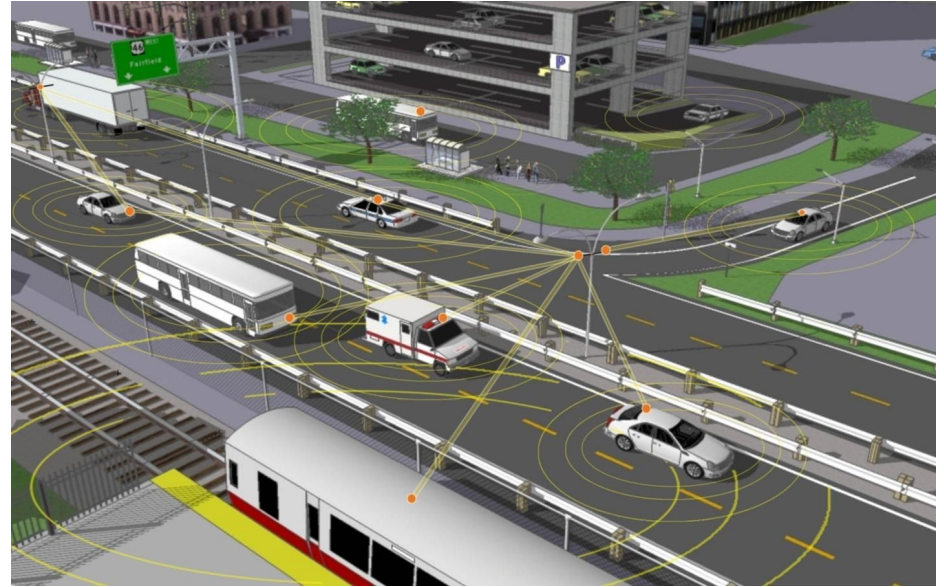
Prof. Hongwei Zhang

Introduction

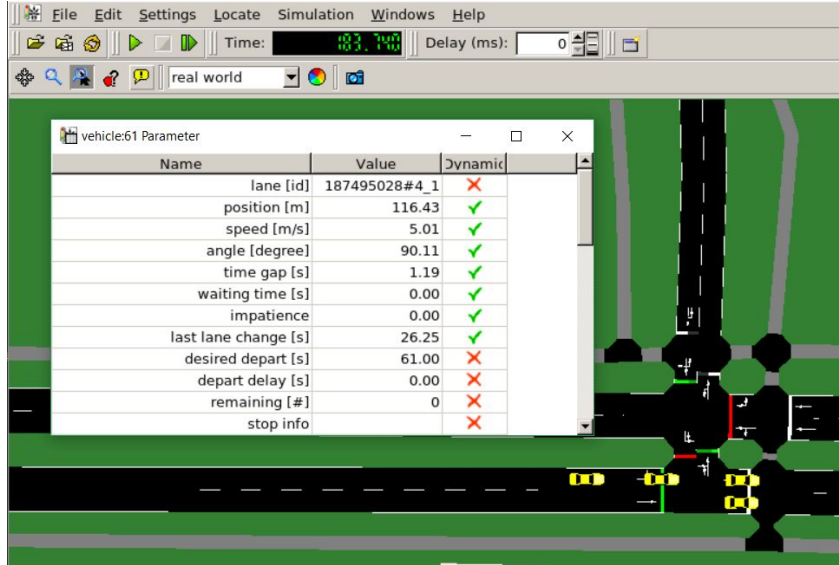
- Problem Statement
- Software Information
- GCS Algorithm
- Implementation
- Testing

Problem Statement

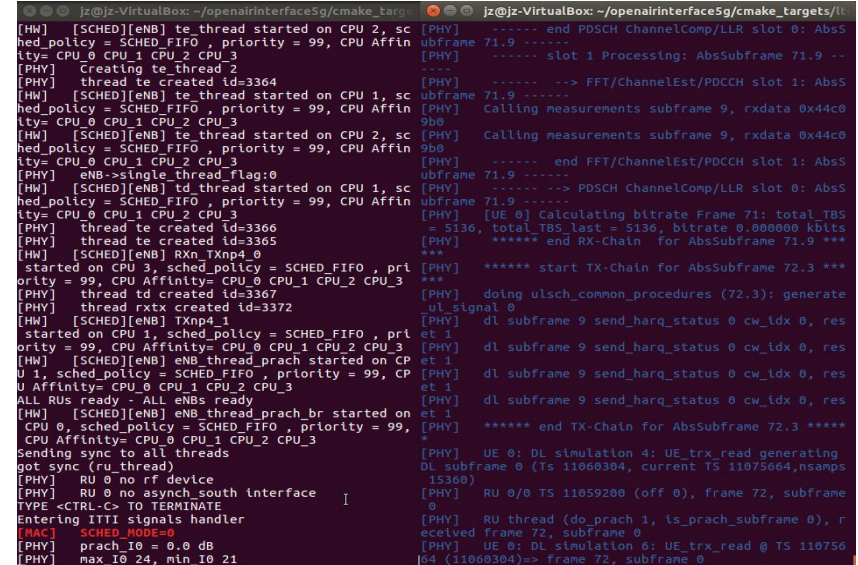
- Interferences
- Reliability
- Geometric Cellular Scheduling



Design - Software



Simulation of Urban Mobility(SUMO)



OpenAirInterface(OAI)

Design - Geometric Cellular Scheduling (GCS)

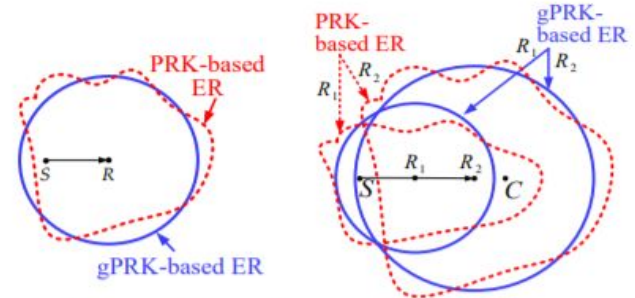
	Static Network	Vehicular Network
Ad-hoc Network	PRKS (PRK model)	CPS (gPRK model)
Cellular Network	UCS (PRK model)	GCS (gPRK model)

PRK model

$$P(C', R) < \frac{P(S, R)}{K_{S,R,T_{S,R}}},$$

gPRK model

$$D(C', R) > D(S, R)K_{S,R,T_{S,R}},$$

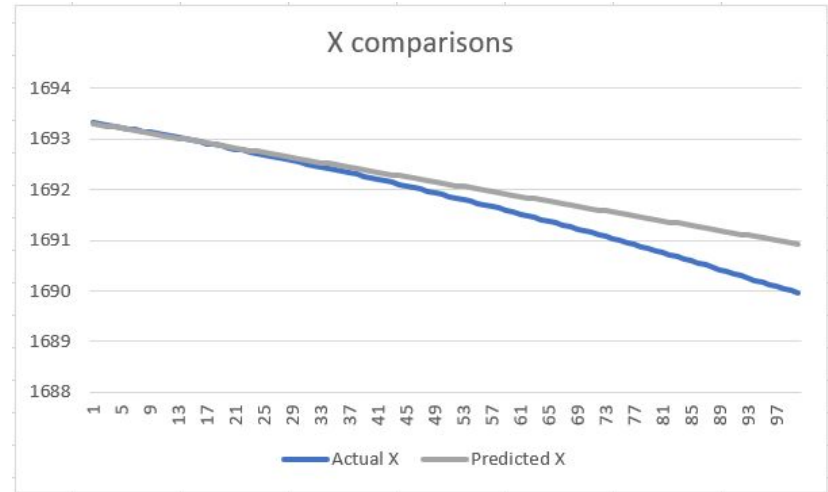


(a) gPRK- vs. PRK-based receiver ER

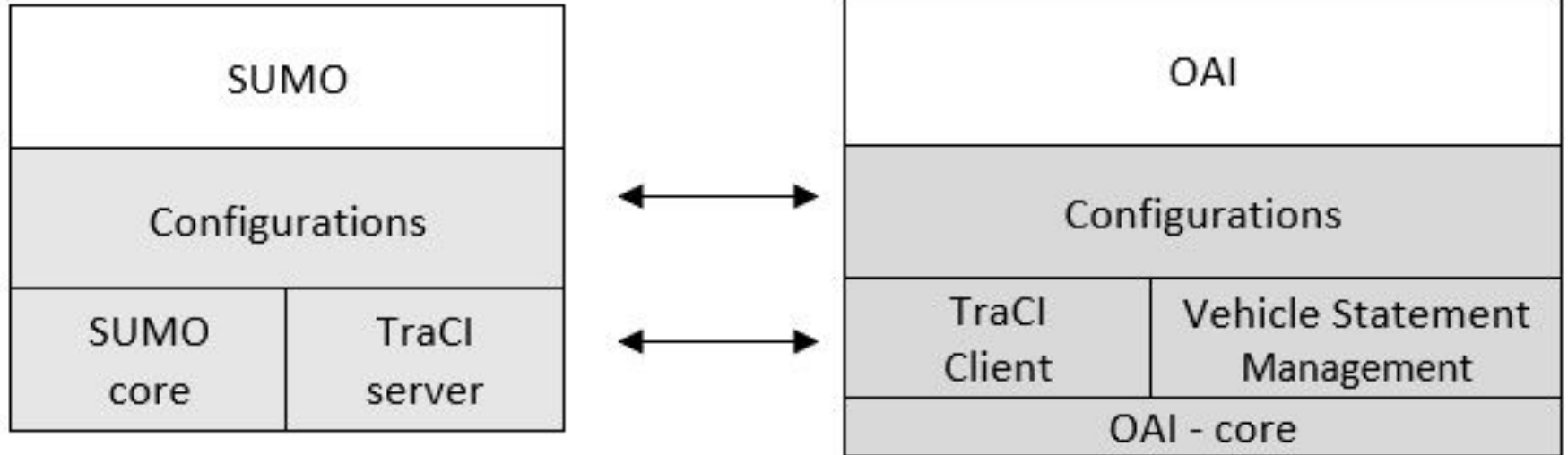
(b) gPRK- vs. PRK-based sender ER

Design - GCS Algorithm

- Estimate the future positions of vehicles.
 - Using Adaptive Cruise Control and Unscented Kalman Filter.
- Interact with SUMO to get vehicle information.
- Use predicted vehicle information to find interference.



Design - Integration

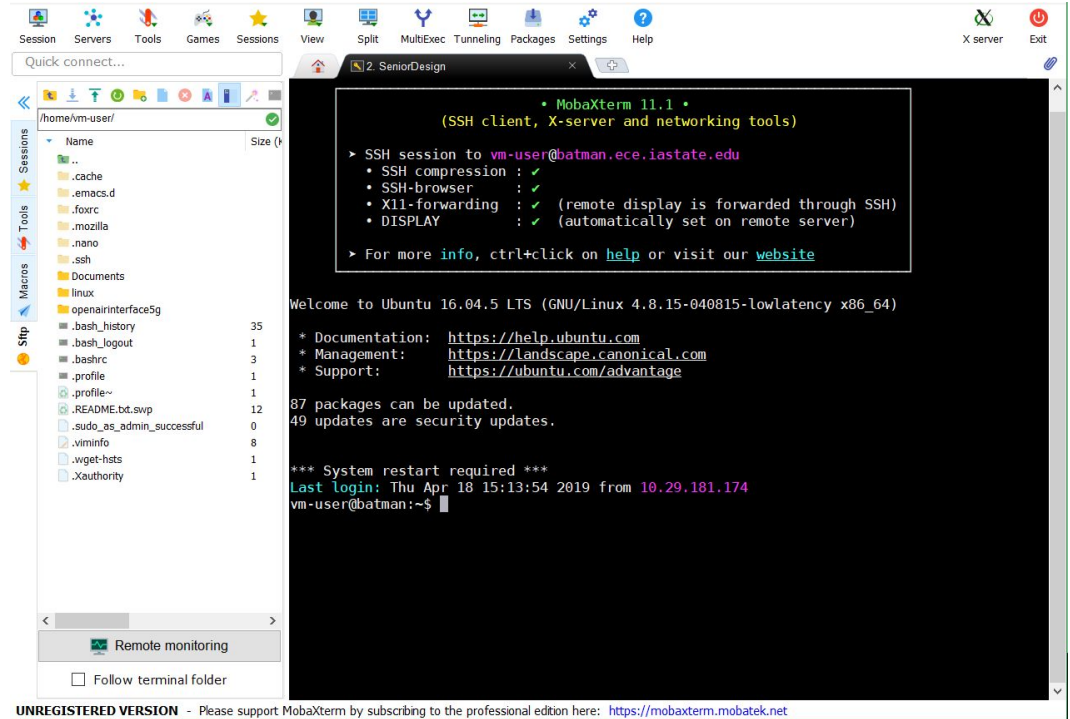


Requirements

- Interference Identification
- Reliability
- Latency
- Concurrency
- Throughput

Implementation

- Setup Server
- Installed SUMO and OAI

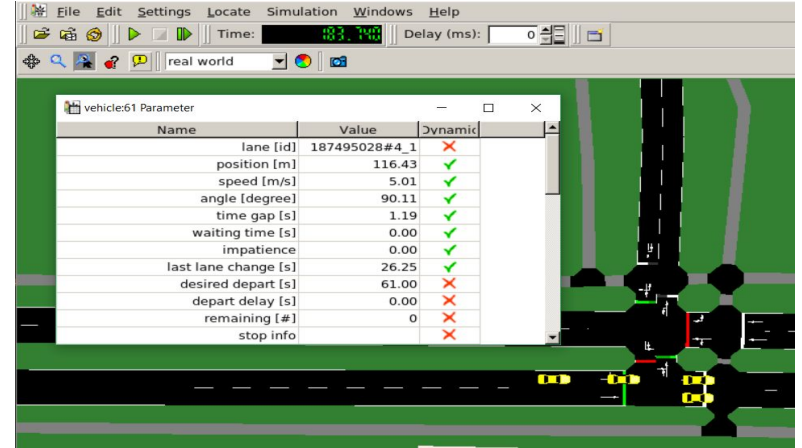
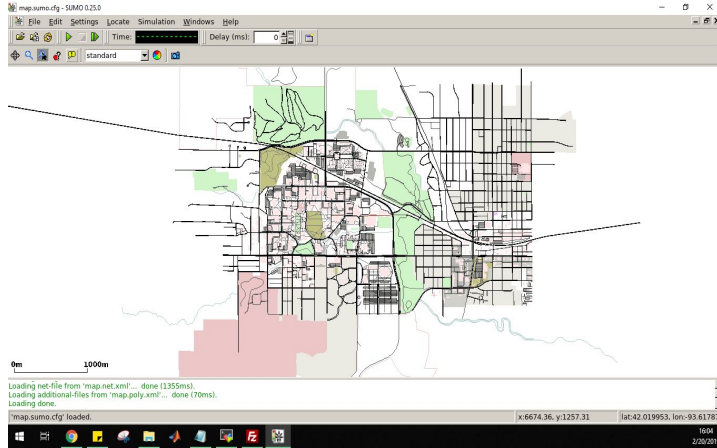


Implementation - cont.

- OAI Update
- UE & eNB Communication

```
jz@jz-VirtualBox: ~/openairinterface5g/cmake_target/
[HW] [SCHED][eNB] te_thread started on CPU 2, sc
hed_policy = SCHED_FIFO , priority = 99, CPU Affin
ity= CPU_0 CPU_1 CPU_2 CPU_3
[PHY] Creating te_thread 2
[PHY] thread te created id=3364
[HW] [SCHED][eNB] te_thread started on CPU 1, sc
hed_policy = SCHED_FIFO , priority = 99, CPU Affin
ity= CPU_0 CPU_1 CPU_2 CPU_3
[HW] [SCHED][eNB] te_thread started on CPU 2, sc
hed_policy = SCHED_FIFO , priority = 99, CPU Affin
ity= CPU_0 CPU_1 CPU_2 CPU_3
[PHY] eNB->single_thread_flag:0
[HW] [SCHED][eNB] td_thread started on CPU 1, sc
hed_policy = SCHED_FIFO , priority = 99, CPU Affin
ity= CPU_0 CPU_1 CPU_2 CPU_3
[PHY] thread te created id=3366
[PHY] thread te created id=3365
[HW] [SCHED][eNB] RXn_TXnp4_0
started on CPU 3, sched_policy = SCHED_FIFO , pri
ority = 99, CPU Affinity= CPU_0 CPU_1 CPU_2 CPU_3
[PHY] thread td created id=3367
[PHY] thread rtx created id=3372
[HW] [SCHED][eNB] TXnp4_1
started on CPU 1, sched_policy = SCHED_FIFO , pri
ority = 99, CPU Affinity= CPU_0 CPU_1 CPU_2 CPU_3
[HW] [SCHED][eNB] eNB_thread_prach started on CP
U 1, sched_policy = SCHED_FIFO , priority = 99, CP
U Affinity= CPU_0 CPU_1 CPU_2 CPU_3
ALL RUs ready - ALL eNBs ready
[HW] [SCHED][eNB] eNB_thread_prach_br started on
CPU 0, sched_policy = SCHED_FIFO , priority = 99,
CPU Affinity= CPU_0 CPU_1 CPU_2 CPU_3
Sending sync to all threads
got sync (ru_thread)
[PHY] RU 0 no rf device
[PHY] RU 0 no asynch_south interface
TYPE <CTRL-C> TO TERMINATE
Entering ITTI signals handler
[MAC] SCHED_MODE=0
[PHY] prach_I0 = 0.0 dB
[PHY] max_I0 24, min_I0 21
[PHY] ----- end PDSCH ChannelComp/LLR slot 0: AbsS
ubframe 71.9 -----
[PHY] ----- slot 1 Processing: AbsSubframe 71.9 --
-----
[PHY] ----- --> FFT/ChannelEst/PDCCH slot 1: AbsS
ubframe 71.9 -----
[PHY] Calling measurements subframe 9, rxdata 0x44c0
9b0
[PHY] Calling measurements subframe 9, rxdata 0x44c0
9b0
[PHY] ----- end FFT/ChannelEst/PDCCH slot 1: AbsS
ubframe 71.9 -----
[PHY] ----- --> PDSCH ChannelComp/LLR slot 0: AbsS
ubframe 71.9 -----
[PHY] [UE 0] Calculating bitrate Frame 71: total_TBS
= 5136, total_TBS_last = 5136, bitrate 0.000000 kbits
[PHY] ***** end RX-Chain for AbsSubframe 71.9 ***
***
[PHY] ***** start TX-Chain for AbsSubframe 72.3 ***
***
[PHY] doing ulsch_common_procedures (72.3): generate
ul_signal 0
[PHY] dl subframe 9 send_harq_status 0 cw_idx 0, res
et 1
[PHY] dl subframe 9 send_harq_status 0 cw_idx 0, res
et 1
[PHY] dl subframe 9 send_harq_status 0 cw_idx 0, res
et 1
[PHY] dl subframe 9 send_harq_status 0 cw_idx 0, res
et 1
[PHY] ***** end TX-Chain for AbsSubframe 72.3 *****
*
[PHY] UE 0: DL simulation 4: UE_trx_read generating
DL subframe 0 (TS 11060304, current TS 11075664, nsamps
15360)
[PHY] RU 0/0 TS 11059200 (off 0), frame 72, subframe
0
[PHY] RU thread (do_prach 1, is_prach_subframe 0), r
eceived frame 72, subframe 0
[PHY] UE 0: DL simulation 6: UE_trx_read @ TS 110756
64 (11060304)>= frame 72, subframe 0
```

Implementation - cont.



- Map of Iowa State Campus
- Data Extraction

Implementation - cont.

$$a_{ACC}(s, v, v_l, \dot{v}_l) = \begin{cases} a_{IIDM}, & \text{if } a_{IIDM} \geq a_{CAH} \\ (1-c)a_{IIDM} + c[a_{CAH} + b \tanh(\frac{a_{IIDM} - a_{CAH}}{b})], & \text{otherwise} \end{cases} \quad (3)$$

where $c \in [0, 1]$ and is usually set as 0.99,

$$a_{CAH}(s, v, v_l, \dot{v}_l) = \begin{cases} \frac{v^2 \dot{a}_l}{v_l^2 - 2s\dot{a}_l}, & \text{if } v_l(v - v_l) \leq -2s\dot{a}_l \\ \dot{a}_l - \frac{(v-v_l)^2 I_{v-v_l \geq 0}}{2s}, & \text{otherwise} \end{cases} \quad (4)$$

$$a_{IIDM} = \begin{cases} a(1 - z^2), & \text{if } v \leq v_0, z = \frac{s^*(v, v - v_0)}{s} \geq 1 \\ a_{free}(1 - z^{(2a)/a_{free}}), & \text{if } v \leq v_0, z < 1 \\ a_{free} + a(1 - z^2), & \text{if } v > v_0, z \geq 1 \\ a_{free}, & \text{if } v > v_0, z < 1 \end{cases} \quad (5)$$

$$a_{free}(v) = \begin{cases} a[1 - (\frac{v}{v_0})^\delta], & \text{if } v \leq v_0 \\ -b[1 - (\frac{v}{v_0})^{a\delta/b}], & \text{otherwise} \end{cases} \quad (6)$$

$$s^*(v, v - v_0) = s_0 + \max(0, vT + \frac{v(v - v_l)}{2\sqrt{ab}}). \quad (7)$$

Initialize with:

$$\begin{aligned} \hat{\mathbf{x}}_0 &= E[\mathbf{x}_0] \\ \mathbf{P}_0 &= E[(\mathbf{x}_0 - \hat{\mathbf{x}}_0)(\mathbf{x}_0 - \hat{\mathbf{x}}_0)^T] \\ \hat{\mathbf{x}}_0^a &= E[\mathbf{x}^a] = [\hat{\mathbf{x}}_0^T \mathbf{0} \mathbf{0}]^T \end{aligned}$$

$$\mathbf{P}_0^a = E[(\mathbf{x}_0^a - \hat{\mathbf{x}}_0^a)(\mathbf{x}_0^a - \hat{\mathbf{x}}_0^a)^T] = \begin{bmatrix} \mathbf{P}_0 & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{P}_v & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{P}_n \end{bmatrix}$$

For $k \in \{1, \dots, \infty\}$,

Calculate sigma points:

$$\mathcal{X}_{k-1}^a = [\hat{\mathbf{x}}_{k-1}^a \quad \hat{\mathbf{x}}_{k-1}^a \pm \sqrt{(L+\lambda)\mathbf{P}_{k-1}^a}]$$

Time update:

$$\mathcal{X}_{k|k-1}^x = \mathbf{F}[\mathcal{X}_{k-1}^x, \mathcal{X}_{k-1}^v]$$

$$\hat{\mathbf{x}}_k^- = \sum_{i=0}^{2L} W_i^{(m)} \mathcal{X}_{i,k|k-1}^x$$

$$\mathbf{P}_k^- = \sum_{i=0}^{2L} W_i^{(c)} [\mathcal{X}_{i,k|k-1}^x - \hat{\mathbf{x}}_k^-][\mathcal{X}_{i,k|k-1}^x - \hat{\mathbf{x}}_k^-]^T$$

$$\mathcal{Y}_{k|k-1} = \mathbf{H}[\mathcal{X}_{k|k-1}^x, \mathcal{X}_{k-1}^v]$$

$$\hat{\mathbf{y}}_k^- = \sum_{i=0}^{2L} W_i^{(m)} \mathcal{Y}_{i,k|k-1}$$

Measurement update equations:

$$\mathbf{P}_{y_k y_k} = \sum_{i=0}^{2L} W_i^{(c)} [\mathcal{Y}_{i,k|k-1} - \hat{\mathbf{y}}_k^-][\mathcal{Y}_{i,k|k-1} - \hat{\mathbf{y}}_k^-]^T$$

$$\mathbf{P}_{x_k y_k} = \sum_{i=0}^{2L} W_i^{(c)} [\mathcal{X}_{i,k|k-1}^x - \hat{\mathbf{x}}_k^-][\mathcal{Y}_{i,k|k-1} - \hat{\mathbf{y}}_k^-]^T$$

$$\mathcal{K} = \mathbf{P}_{x_k y_k} \mathbf{P}_{y_k y_k}^{-1}$$

$$\hat{\mathbf{x}}_k = \hat{\mathbf{x}}_k^- + \mathcal{K}(\mathbf{y}_k - \hat{\mathbf{y}}_k^-)$$

$$\mathbf{P}_k = \mathbf{P}_k^- - \mathcal{K} \mathbf{P}_{y_k y_k} \mathcal{K}^T$$

where, $\mathbf{x}^a = [\mathbf{x}^T \mathbf{v}^T \mathbf{n}^T]^T$, $\mathcal{X}^a = [(\mathcal{X}^x)^T (\mathcal{X}^v)^T (\mathcal{X}^n)^T]^T$, λ =composite scaling parameter, L =dimension of augmented state, \mathbf{P}_v =process noise cov., \mathbf{P}_n =measurement noise cov., $W_i = w_i \mathbf{c}_i \mathbf{c}_i^T$ as calculated in Eqn. 15.

Implementation - cont.

```
double a_CAH(double velocity, double other_velocity, double s, double A){
    double effective_a;
    double return_value;
    int I = 0;
    if( A < other_velocity){
        effective_a = A;
    }
    else{
        effective_a = other_velocity;
    }
    if((other_velocity * (velocity - other_velocity)) <= (-2 * s * effective_a)){
        return_value = pow(velocity, 2) * effective_a;
        return return_value / (pow(other_velocity, 2) - (2 * s * effective_a));
    }
    else{
        if((velocity - other_velocity) >= 0){
            I = 1;
        }
        return_value = pow((velocity - other_velocity), 2);
        return_value = return_value * I;
        return_value = return_value / (2 * s);
        return effective_a - return_value;
    }
}

//A predictive model for a vehicles relative acceleration given information on a lead vehicle
double a_ACC(double current_lat, double current_long, double other_lat, double other_long,
    double velocity, double other_velocity, double desired_velocity, double A){

    double s = distance_between(current_lat, current_long, other_lat, other_long);
    double predictive_s = predictive_distance(current_lat, current_long, other_lat, other_long, velocity, other_velocity,A, s);
    double IIDM = a_IIDM(predictive_s, s, velocity, desired_velocity, A);
    double CAH = a_CAH(velocity, other_velocity, s, A);
    double c = .99;
    if(IIDM >= CAH){
        return IIDM;
    }
    else{
        return ((1 - c) * IIDM) + c * (CAH + (comfort_deAcc * tanh((IIDM - CAH)/ comfort_deAcc)));
    }
}
```

Implementation - Pending & Uncompleted

- Communications between SUMO and OAI
- Unscented Kalman Filter for future position estimations
- Integration of position estimation math with OAI
- Testing of modified OAI code to verify correctly working scheduling.

Testing and Evaluation

OAI Stress Testing	Number of UEs	2
	Number of eNBs	1
SUMO Simulation	Number of Vehicles	3600
	Testing Area	Iowa State Campus
GCS a_ACC	Tested without Kalman Filter. Outputs expected results as defined by the algorithm formulas	
GCS Approximation	Outputs similar latitude and longitude to future SUMO data	

Risks and Complications

- OAI and SUMO setup issues
- Lack of computing power
- Open source software (OAI)
- Variety and depth of project topics
- Software focused ending

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