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

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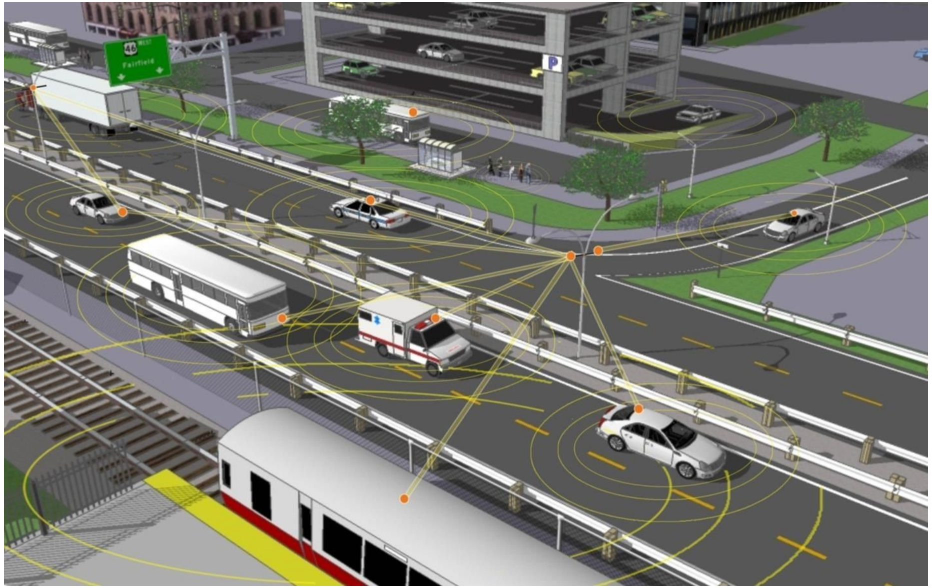
Introduction

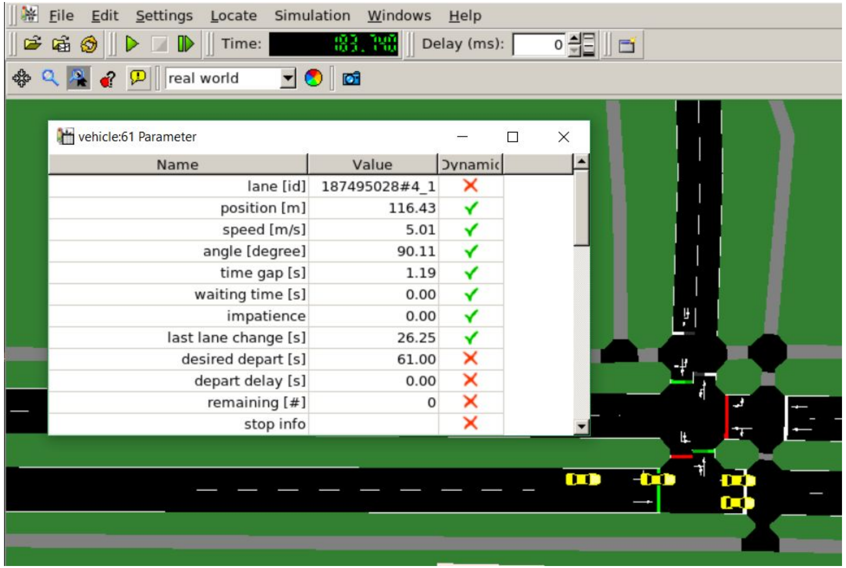
- Problem Statement
- Software Information
- GCS Algorithm
- Implementation
- Testing

Problem Statement

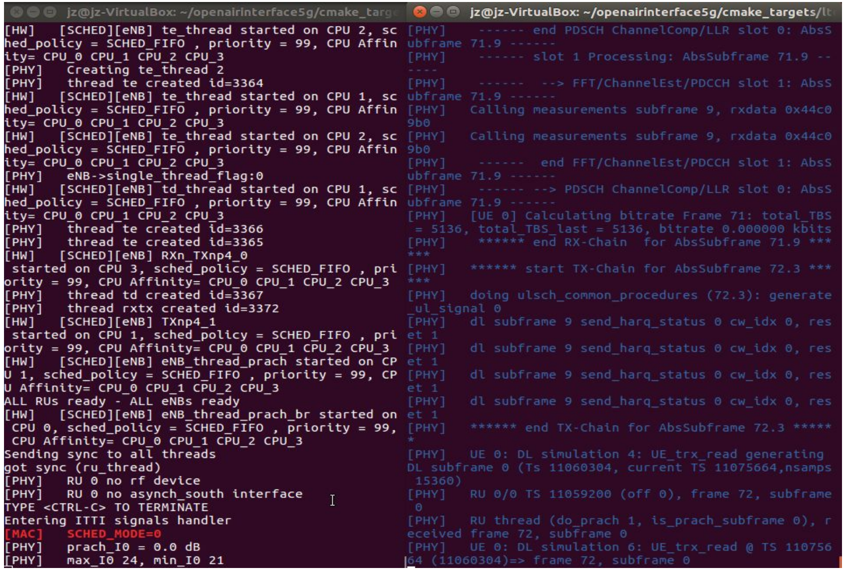
- Interferences
- Reliability
- Geometric Cellular Scheduling



Design - Software



Simulation of Urban Mobility(SUMO)



OpenAirInterface(OAI)

Design - Geometric Cellular Scheduling (GCS)

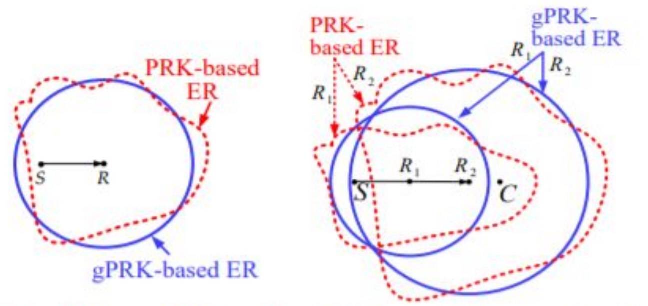
	Static Network	Vehicular Network
Ad-hoc Network	PRKS (PRK model)	CPS (gPRK model)
Cellular Network	UCS (PRK model)	**GCS** (gPRK model)

PRK model

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

gPRK model

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



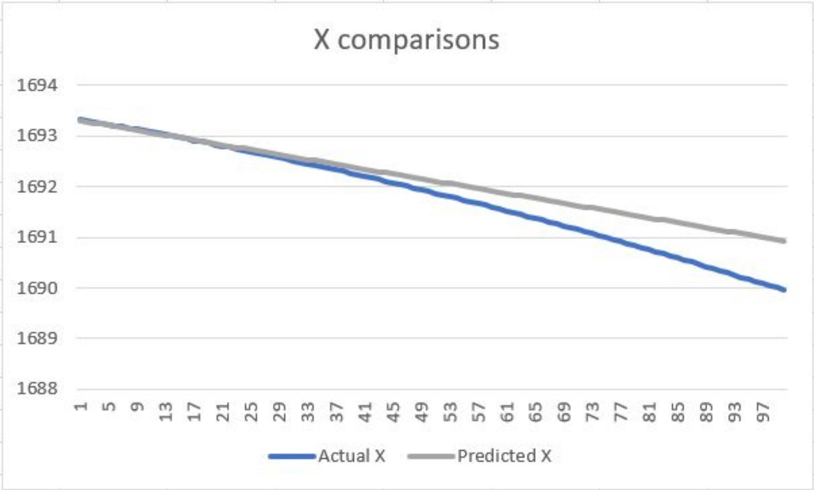
(a) gPRK- vs. PRK-based receiver ER (b) gPRK- vs. PRK-based sender ER

Design - GCS Algorithm

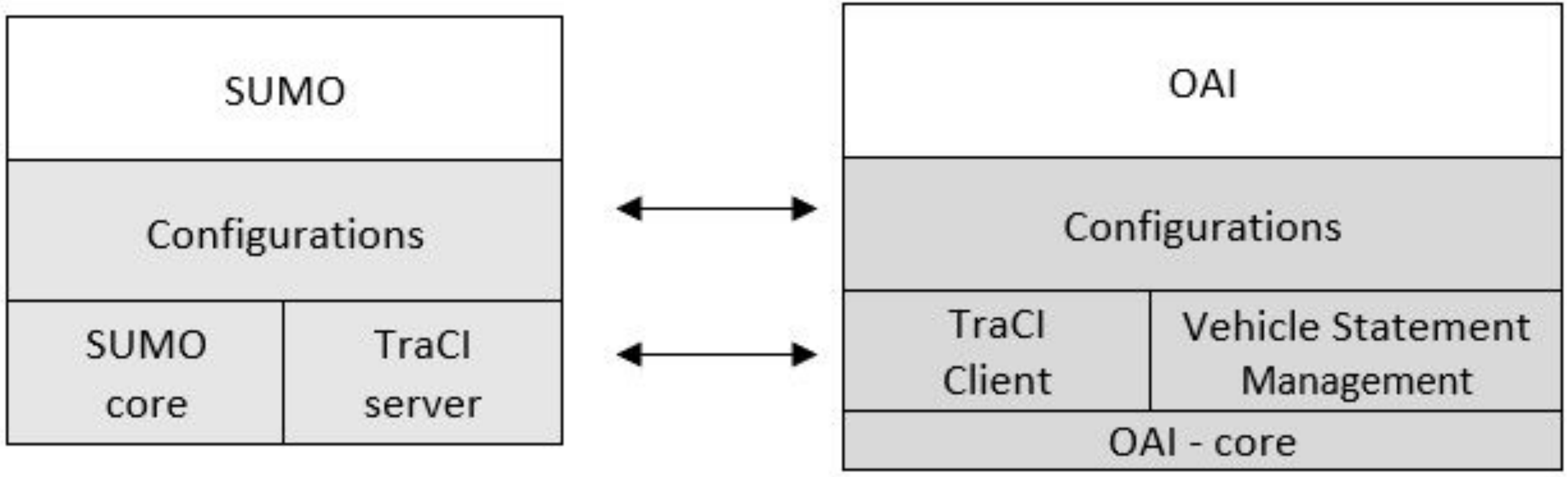
- Estimate the future positions of vehicles.
    - Using Adaptive Cruise Control and Unscented Kalman Filter.

- Interact with SUMO to get vehicle information.

- Use predicted vehicle information to find interference.



Design - Integration

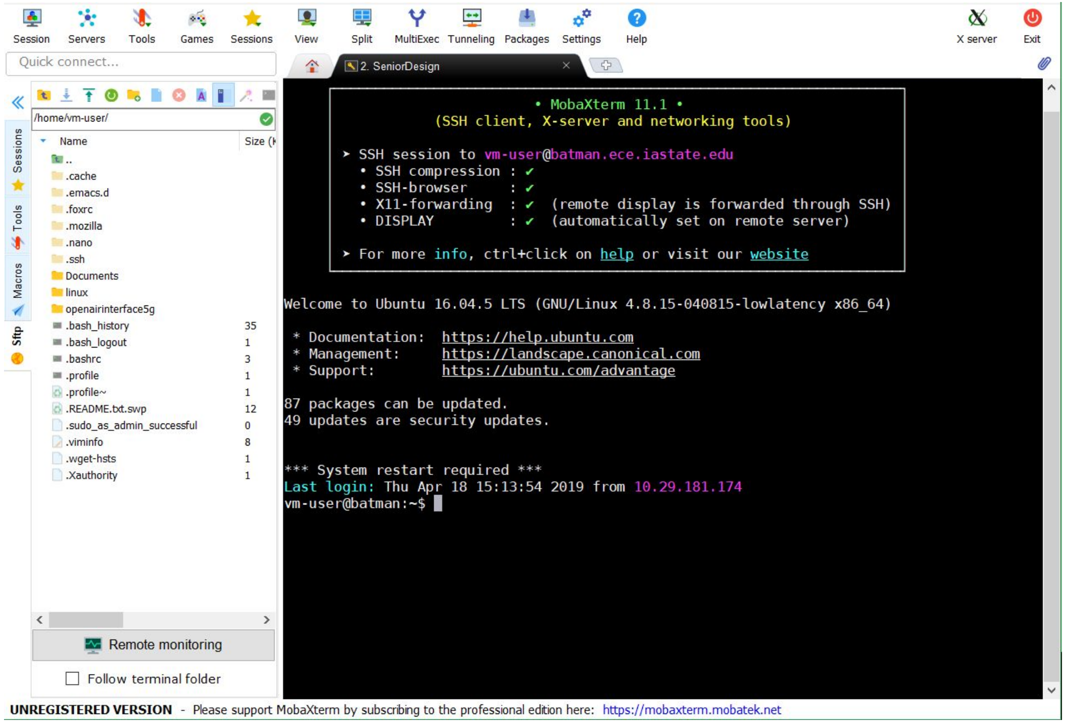


Requirements

- Interference Identification
- Reliability
- Latency
- Concurrency
- Throughput

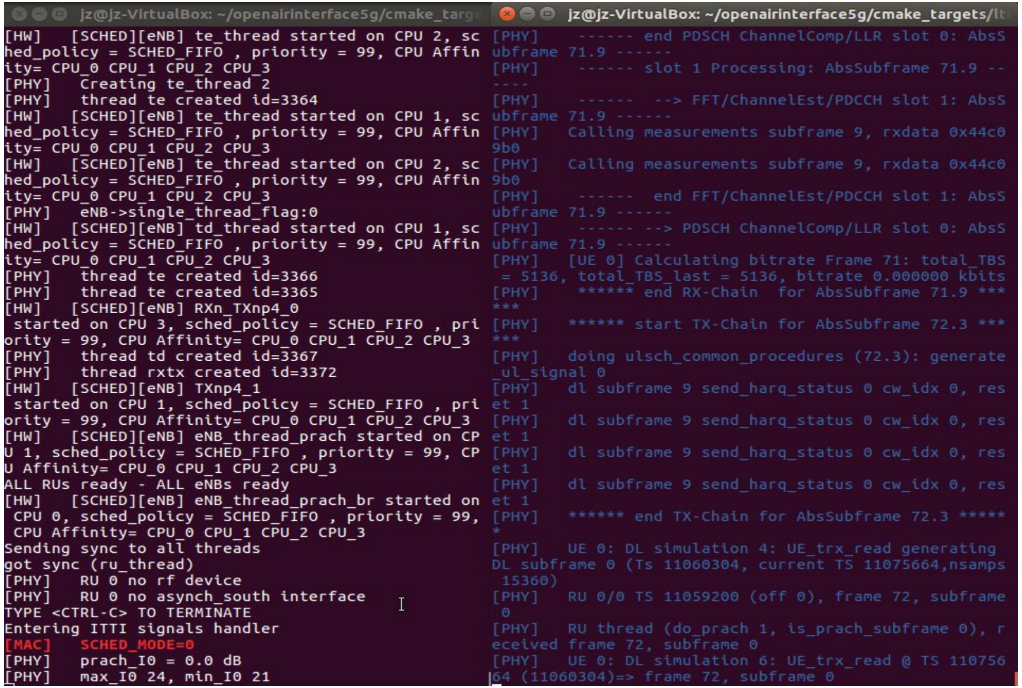
Implementation

- Setup Server
- Installed SUMO and OAI

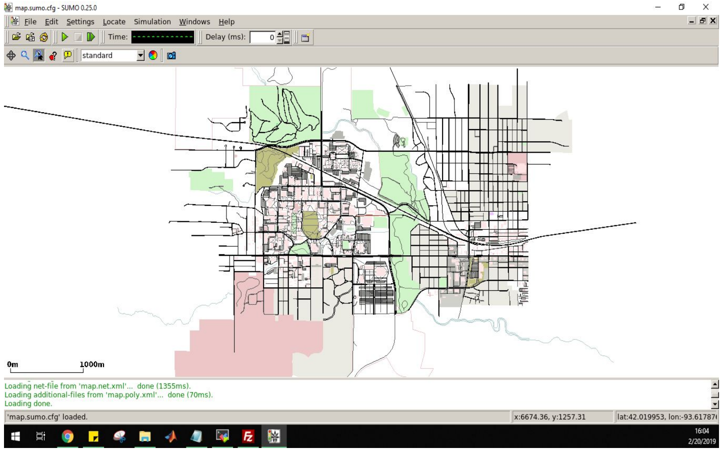


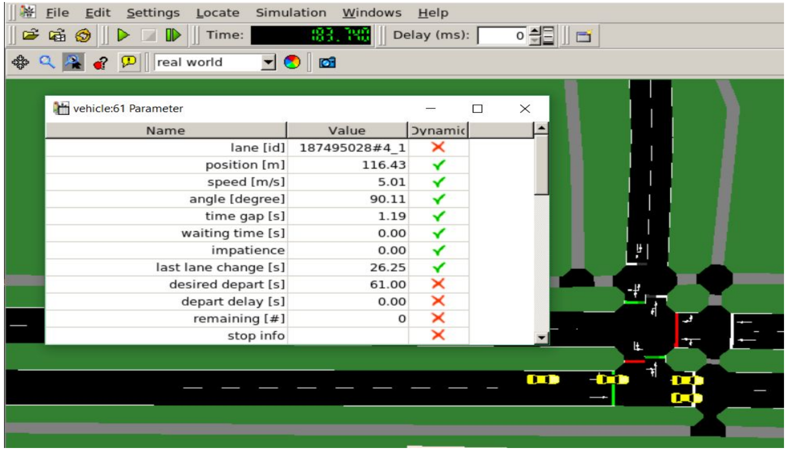
Implementation - cont.

- OAI Update
- UE & eNB Communication



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,

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

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

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

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

Initialize with:

$$\hat{\mathbf{x}}_0 = E[\mathbf{x}_0]$$

$$\mathbf{P}_0 = E[(\mathbf{x}_0 - \hat{\mathbf{x}}_0)(\mathbf{x}_0 - \hat{\mathbf{x}}_0)^T]$$

$$\hat{\mathbf{x}}_0^a = E[\mathbf{x}^a] = [\hat{\mathbf{x}}_0^T \; \mathbf{0} \; \mathbf{0}]^T$$

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

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

Calculate sigma points:

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

Time update:

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

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

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

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

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

Measurement update equations:

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

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

$$\mathcal{K} = \mathbf{P}_{\mathbf{x}_k \mathbf{y}_k} \mathbf{P}_{\tilde{\mathbf{y}}_k \tilde{\mathbf{y}}_k}^{-1}$$

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

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

where, $\mathbf{x}^a = [\mathbf{x}^T \; \mathbf{v}^T \; \mathbf{n}^T]^T$, $\boldsymbol{\mathcal{X}}^a = [(\boldsymbol{\mathcal{X}}^x)^T \; (\boldsymbol{\mathcal{X}}^v)^T \; (\boldsymbol{\mathcal{X}}^n)^T]^T$, λ=composite scaling parameter, L=dimension of augmented state, $\mathbf{P_v}$=process noise cov., $\mathbf{P_v}$=measurement noise cov., W_i=weights 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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