Electric Vehicles and Their Impact on Trustworthy Power Grid Informatics

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Outline

- Motivation
- Challenges of EVs
  - EV Problems discussed at IEVC'14
    - Wireless charging
    - Electrification of roads
    - EV Batteries
    - Standards
- Impact on Power Grid Informatics caused by EVs
- Conclusions

Motivation (Why EVs?)

Beijing pollution

New York Pollution

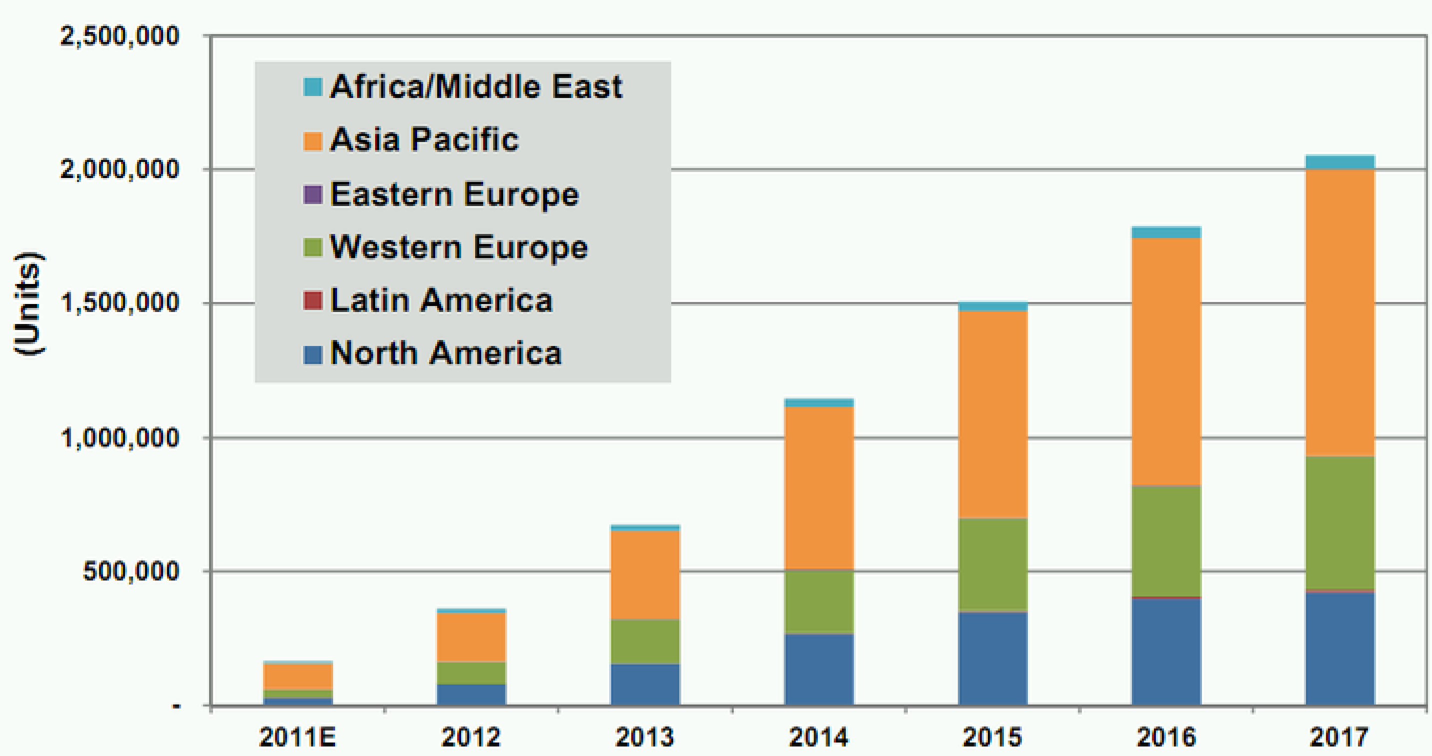
Paris pollution

LA Pollution vs Cheyenne

Motivation

- Increasing popularity of Electric Vehicles (EVs)
- Limitation: access to public charging facilities.

Chart 1.1 Total EV Charging Station Unit Sales by Region, World Markets: 2011-2017



(Source: Pike Research)

http://www.greencarcongress.com/2011/08/pikeevse-20110824.html

Stakeholders

Energy Providers: Distribution and Generation Infrastructure of Electricity

National Policy Makers

Road Infrastructure Providers

EV Makers: Cars, Trucks, Busses, Motorcycles, Trains

Urban City Transport Planners, Logistics, …: Planning Electrification Infrastructure

IT Organizations: IT Infrastructure

Players in USA

- Car Companies:
  - Toyota (USA Division)
  - Ford Motor Company (crowd-sourced energy)
- IT/Telecom Companies:
  - Qualcomm (wireless charging for EV and PHEV)
  - Cisco (network infrastructure and connectivity associated with electrical charging)
  - IBM Software Group (Automotive 2015 Project)
- Universities:
  - Ohio State University (**Major Center on EVs and Transportation** – Three Land Speed Record Electric Cars)
  - University of California, Davis (Batteries)
  - University of Michigan (wireless charging)
  - Clemson University (**Major Center on Transportation** - Urban Mobility Systems)
  - Oregon State University (EV power electronics)
  - University of Colorado at Boulder (EV power electronics)
  - USC (power grid and EV)
  - Virginia Tech (power grid and EV)
  - New York University (wireless charging)
- National Labs:
  - Oak Ridge National Laboratory
- Service Companies
  - Transportation Power Solutions (division in RES – Renewable Engineering Systems)

CHALLENGES OF ELECTRIC VEHICLES

Challenges of EVs

- Electric mobility Beyond 2020!!
  - Eco-friendliness, safety, comfort, efficiency
- EV Charging
  - Charging Stations
  - Static Wireless Charging
  - Dynamic Wireless Charging
- Electrification of Road Infrastructure
- Design of Electric Vehicles themselves
  - Battery (size, weight, temperature, capacity)
  - Speeds of EV – 1 and 2 speed vehicle optimal for passanger cars, trucks may need 3 speeds (higher gears)
- Standards

EV Charging - Charging Stations (1)

- In USA by 2020 first stage of major EV deployment
  In form of **Hybrid Plug-in Electric Vehicles (PEV)**
- Volvo anticipates huge Hybrid EV technology revenue increase
- Pike Research forecasts by 2017
  - 1.5 M of charging stations
  - 5.1 M PEVs in USA
  - EV supply equipment (EVSE) drops by 37% (Gartner)

- Car Metrics to consider
  - BMWi3 car
    - 12.9KW per 100 km
    - acceleration time 0-100km/h takes 7.2 seconds
    - Number of speeds: 1 speed (corresponds to 1 gear)
    - Number of miles per battery

http://www.greencarcongress.com/2011/08/pikeevse-20110824.html

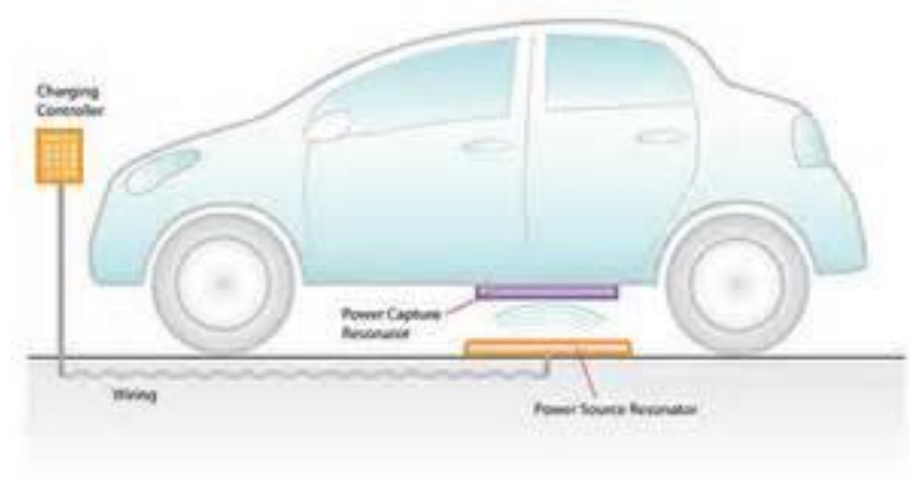
Charging Stations (2)

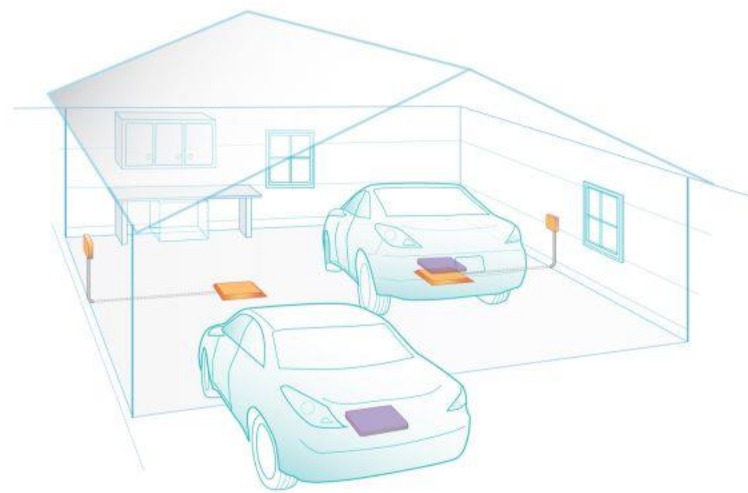
- Challenge: Who installs charging stations?
  - Case study in Brussels:
    - On public land (e.g., public parking space) only utility company can install charging stations; utility charges for electricity
    - Parking company 3rd party should only charge for space
      - But often parking company charges for parking space and usage of charging station; user pays twice
    - On private land (e.g., private garage) 3rd party company installs charging station and charges for electricity

Charging Stations (3)

- Challenge: More PHEV than charging stations
  - Do we establish reservation system?
  - What will happen to other drivers?
  - Is inductive charging the solution?

EV Charging - Static Wireless Charging (1)





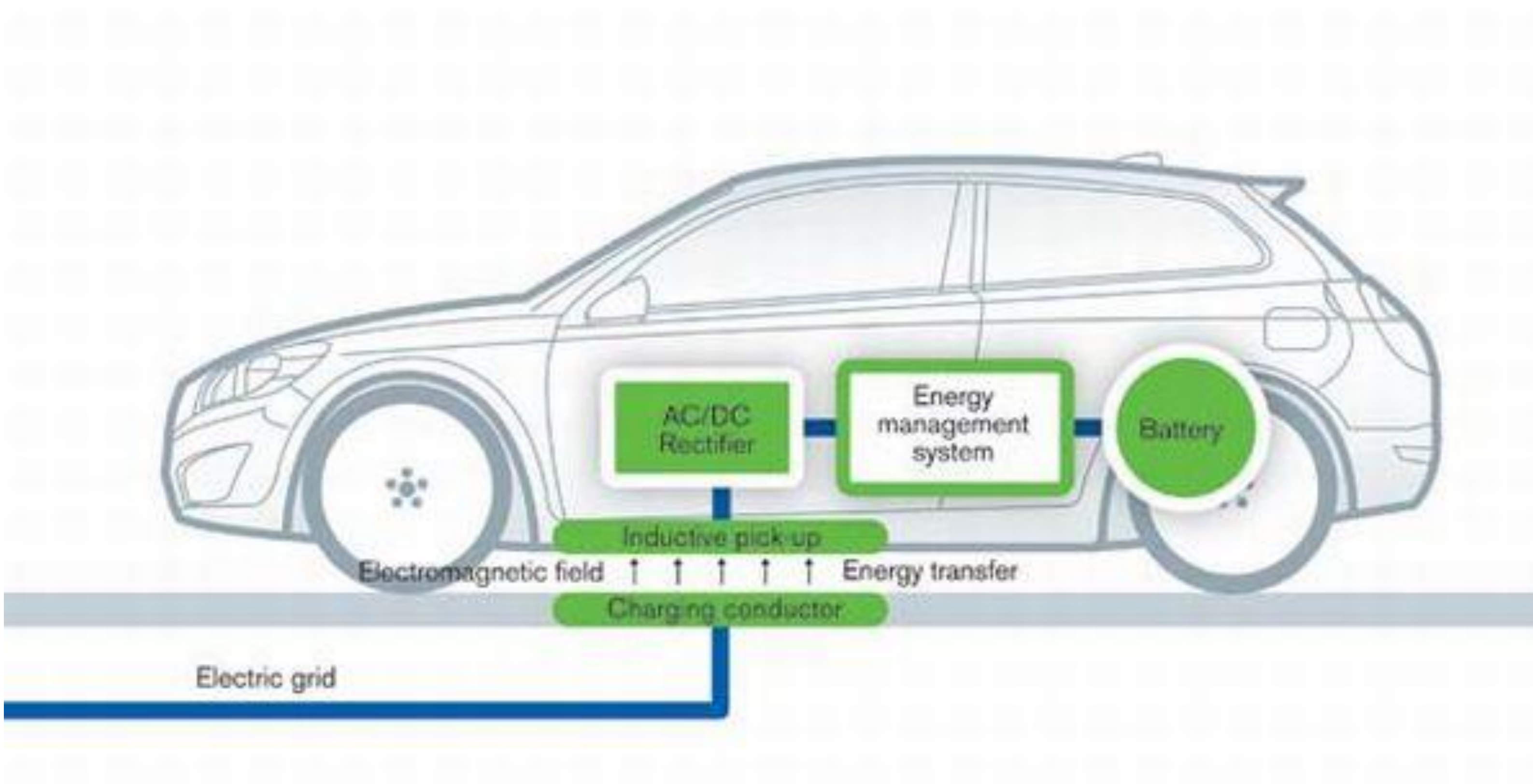
Static Wireless Charging (2)

- First paper about wireless charging by **Tesla 1908 !!**
- Technology: ICET – Inductive Contactless Energy Transfer
- Challenges: weak coupling factor, lower efficiency, high magnetizing
- **Solution: bidirectional inductive contactless energy transfer (CET)**
- CET systems used for
  - Sensor actuators (microwatt power range)
  - EVs (hundreds kilowatts)
- Current efficiency of ICET
  - 80-95% for 10-40cm distance

Static Wireless Charging (3)

- Challenge: People are concerned regarding safety
  - Electric power is transferred through air
  - Tests are going on at ORNL
- Challenge: Long Charging

EV Charging - Dynamic Wireless Charging (1)



Dynamic Wireless Charging (2)

- Technology: Dynamic Wireless Power Transfer (D-WPT)
- Solutions:
  - By ORNL – first vehicle that does D-WPT
    - They work with
      - Evatran LLC
      - CU-ICAR – Clemson University International Center for Automotive Research
      - Toyota Motor Co.
    - They demonstrated
      - dynamic WPT and validated 6.6 KW capable wireless power transfer apparatus at 85% efficiency
      - Complete integration design and vehicular integration

Dynamic Wireless Charging (3)

- Solutions:
- Italy: FABRIC project
  - 200m test track, 20m long coils, 20KW
- France: Qualcomm, Vedecom
  - 100m test track, 85 KHz, > 20KW

Dynamic Wireless Charging (4)

- Challenge: Impact on EV speed
  - if we have 2 m long coils of 20 KW, one needs to go slowly at 36 km/h
  - If one goes at 108km/h, one has only 200ms charging time
- Challenge: Impact on Power Grid
  - Simulation study by FABRIC project:
    - If one considers average 10 EV/km/lane over 1 hour with 500 simulated EVs with max capacity 30 EV/km/lane, then one can achieve 2-8 MW load demand
    - We will need energy storage system if demand fluctuation which will be the case
    - Energy storage systems can minimize demand variability
      - Overall peak load reduction will be less expensive
    - Load shaping and shaving is needed!!!

Dynamic Wireless Charging (5)

- Further Challenges:
  - Communication latency
  - Infrastructure issues for Power grid distribution
  - Coil sequencing
- Electric roads may need solar panels next to the road to provide electricity

Dynamic Wireless Charging (6)

- Pros:
  - Smaller battery
  - Cheaper EV
  - Extended driving range
  - Extended battery lifetime
  - Energy efficiency
  - Comfort
  - Increased mobility
  - No visual pollution
- Cons
  - Expensive infrastructure

Electrification of Road Infrastructure (1)

- ORNL is conducting dynamic roadway projections
  - Estimate cost and impacts for electric roadway given
    - Current vehicle information from supporting lab data
    - Current electric vehicles
  - Estimate cost and impact for electrified roadway given
    - 40 miles per hour vehicular speed
    - Charging pads with 11 KW for small vehicle to keep it charged
- First Results of Projections for Atlanta
  - If we consider 25-30KW, estimated 30% lane coverage, it would cost $2.8M per Mile of electrified road per lane

Electrification of Road Infrastructure (2)

- Roadmap of electrification
  - 0% electrified roadways for EV cars in 2020
    - By 2020 smart eVehicle (Hybrid)
    - By 2022 50% increase of PHEVs in Europe (forecast)
    - By 2025 integrated system (information cloud + driver commands + vehicle sensory data = integrated energy management)
  - Building business cases towards 2050
    - 4 US Metro Areas
      - LA - Long Beach
      - San Francisco-Oakland
      - San Diego Area
      - Atlanta Area
    - Base case of 100 KW and 30KW WPT
  - Bus (and trucks) lanes will be first go towards electrification
    - stable routes
  - Trains are already electric

Electrification of Road Infrastructure (3)

- Challenges:
  - Cost of dynamic WPT on vehicle
    - What is the impact of WPT on vehicle (size of battery)?
  - How do we pay for road electrification?
    - Road use cases – toll roads, taxes
  - Where do we place charging pads?
    - Case study – I-75 South Atlanta

Electrification of Road Infrastructure (4)

- Challenges for Wireless Charging:
  - Road material for on-the-road charging
  - How do we deal with water, snow, sand, ice, clay, etc on roads?
    - There is loss when roads are wet. We road causes electromagnetic loss)
    - We need different material to minimize loss even in wet conditions.
  - How do we deal with structural integrity of road?
    - Roads can crack, have rutting problems
    - We need device to test roads for structural integrity.

Source: KTH Smart Road Infrastructure Project

EV Battery

- Challenge: Size of battery
  - If we have charging stations, we need larger batteries
  - If we have charging pads (WPT), we would need smaller batteries
    - Desirable 1.6 KW batteries or even 1.5 KW
- Impact of WPT on Battery Size
  - We will need coils spaced close to each other
  - We will need to have sensors on coils, to enable coils to be energized and controlled with speed,
  - Sensors would know how fast you go and energize accordingly
  - With sensors, one starts with first coil and then the next will be fired up dynamically
    - Energy savings since coils will not be needed to be on constantly

EV Battery (2)

- Challenge: Cost of Battery
  - Cost target of $250 per KWh is unlikely to happen by 2020
    - According to Dr. Bernarsch, CEO Virtual Vehicle Research Center
  - However, overall prices are going down
    - TESLA-S2 battery price is going down
- Challenge: Energy and Thermal Management in EV
  - With intelligent and Integrated energy and Thermal management in EV we can increase driving range

Standards (1)

- SAE J2954 Standard – Wireless Charging
  - Combining DSRC/RFID Wireless Charging J2954 Communications Subgroup
    - In Vehicle Navigation
    - Electric charging stations
    - Vehicle diagnostic and performance
    - Charging and ePayment solutions
  - DSRC 5.9 GHz ~300m range
- IEC 61851 Standard - EV Conductive Charging System
  - IEC 61851-24 : digital communication between EV charging station and electric vehicle for control of charging

Standards (2)

- Joint Project between ISO and IEC – dedicated to interoperability and safety in wireless magnetic interaction vehicle interaction
  - ISO TC22/SC21 and IEC TC 69
  - ISO 19363 – Magnetic field wireless power transfer – interoperability and safety requirement
  - IEC JPT 61980 – electric vehicle wireless power transfer (WPT) system
    - Specific requirements for communication between EV and infrastructure with respect to WPT systems
  - ISO/IEC 15118 – road vehicle to grid communication interface (all network protocol stack layers defined
- All standards at this point provide safety requirements and protection against electrification
- NO protection against cyber-attacks yet

Summary of Challenges of EV Systems

- Challenge: Cost
  - Number of EVs must go up
  - Charging technologies must improve
  - Weight and size of batteries must go down
  - Cost of electrification
  - Standardization is necessary
- Other challenges not discussed in this talk but very much of interest to EV Car Manufacturers:
  - **Automated vehicle driving**
  - **Connected vehicles**

IMPACT ON POWER GRID INFORMATICS

What is Power Grid Informatics?

- **Power Grid Informatics** is the science of cyber-information about power grid. It studies the structure, algorithms, behavior, and interactions of power grid physical systems and artificial cyber systems (cyber-physical systems) which store, process, access and communicate information. The field considers the interaction between human power grid/utility operator and/or stakeholder and power grid information systems alongside the construction of computer interfaces.
- **Trustworthy Power Grid Informatics** encompasses the study of systems that represent, process and communicate digital information in real-time, reliable, secure and private manner (availability, integrity, confidentiality, privacy).

Cyber-Physical Components

- **Road**:
  - Sensors on/in the roads (coils) in case of dynamic wireless charging, signaling, other road functions
  - Road Side Units (RSU) next to the road for capturing, processing and communicating wirelessly sensory information (cell towers, wireless access and processing points)
- **EV Car**:
  - Mobile smart meter to measure charging levels and usage levels
  - Other sensors monitoring other functions of car services
- **Power Grid Utility:**
  - Cloud computing and storage to store and process all the sensory information and provide power grid services
- **Road Services and 3rd Party Services**:
  - Cloud computing and storage to store, process and share related contextual information offered in conjunction with power grid services

Impact on Power Grid Informatics – Processing

- Challenge: Provide IT Services in Power Grid Informatics for EVs
  - Represent and Process Information via Algorithms towards
    - Accurate range estimation
    - Navigation
      - Cooperative IT system allows for robust traveling via re-routing
    - Assignment of charging stations
    - Placement of charging stations and charging pads
- Challenge: Enable Seamless Information Integration related to Power Grid Infrastructure, Trustworthy IT Infrastructure, EV Design, and Road Infrastructure (with wireless charging)
  - Large number of sensors (EV, road, power grid, people)
  - Different information representation
  - Different communication technologies
  - Different digital and energy storage capabilities
  - Mobility issues
  - Different security and privacy capabilities and demands

Impact on Power Grid Informatics - Processing

- Challenges for Business Models: Big Data
  - Cost-benefit analysis
  - Environmental life-cycle assessment
- Challenges for Charging Concepts: Real-Time
  - Vehicle authorization
  - Charging profile negotiation
  - Monitoring of power transfer while EV is over pads
  - Billing and payment
  - Coordination of WPT hardware with information control transmission

Impact on Power Grid Informatics – Processing

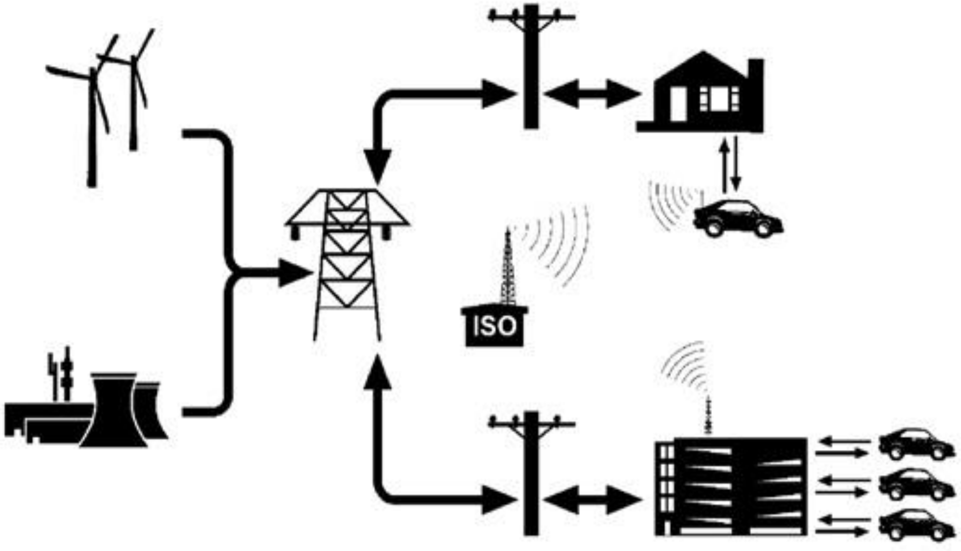
- Intelligent Power Management inside EV
  - In PHEV, we have auxiliary electrified system (air supply system, power steering, entertainment system)
  - Multi-physical system, auxiliary energy buffers, local constraints, controlled by real-time CPS control system
- **Solution:** Game Theory Approach:
  - Energy suppliers vs energy consumers in PHEV
  - Energy suppliers: Engine, electric motor, battery
  - Energy consumers: auxiliary system
  - Game-Theory guides decisions when each player scheduled its activation and deactivation on a prediction horizon

Impact on Power Grid Informatics - Access

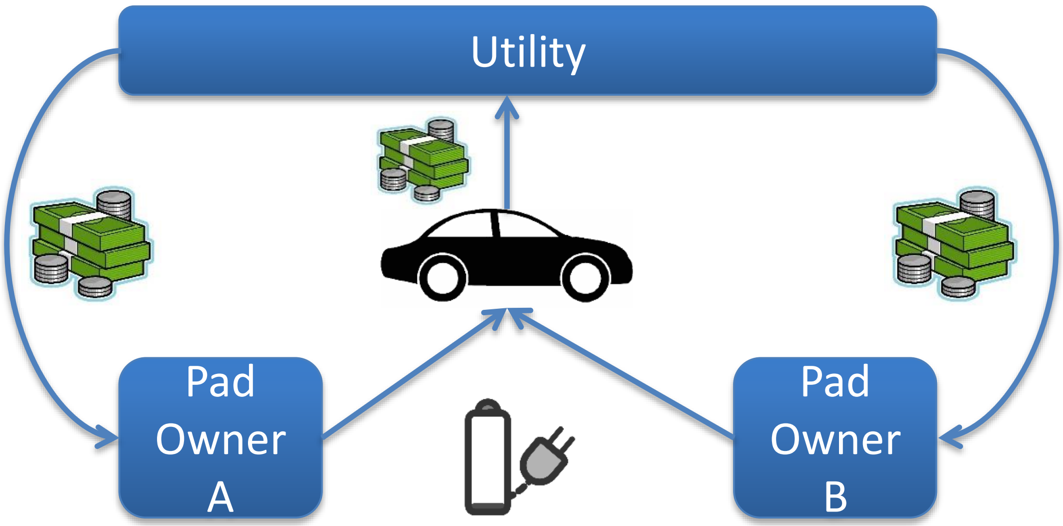
- Make available power grid information with high integrity to ensure:
  - Power service continuity
  - Flexibility and extendibility,
  - Monitoring of demand growth
  - Electrical efficiency
  - Operational efficiency
  - Power quality
- Deal with large power fluctuation due to power transfer design, effect of traffic conditions
    - Deal with Variable number of vehicles in lanes in case of WPT
- **Solution:**
  - Platooning of vehicles might reduce peak load demand via coordinated power transfer
  - Adequate lane design must happen
  - Energy storage and traffic control will help

Impact on Power Grid Informatics - Communication

- Vehicle-to-Grid Communication
- Challenges:
  - Real-time Digital Communication of Status/Control Informatio
    - Availability and integrity of information
  - Real-time Authentication
    - Identification, authorization, authentication, verification
  - Location Privacy

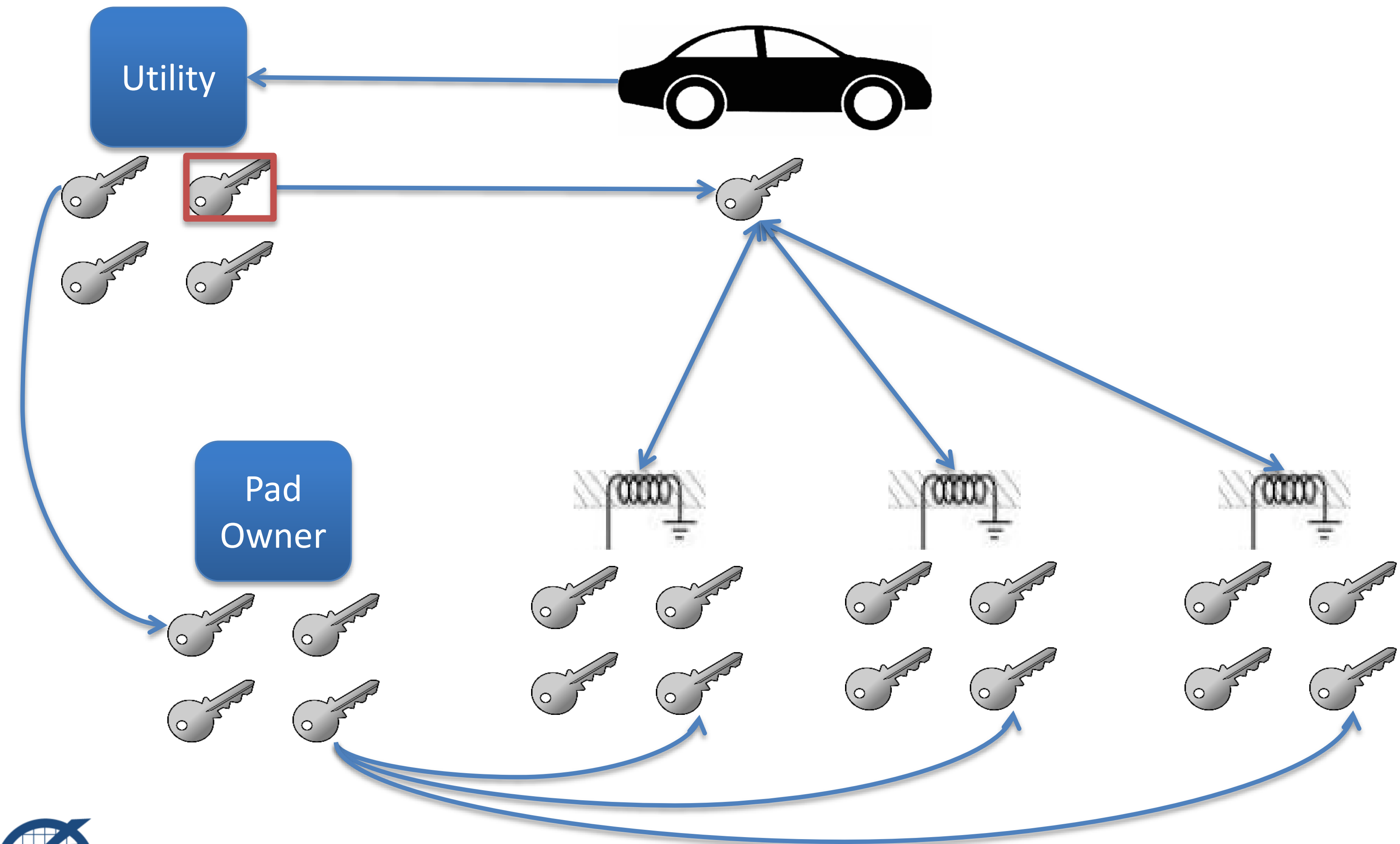


Solution for Roaming Service Model



- EV
  - subscribes to the utility
  - makes monthly payment to the utility
- Utility
  - manages subscribing EV's information
  - bills the EV monthly
- Pad Owner
  - installs charging pads
  - provides dynamic charging service
  - may receive energy from some other utility

One Possible Solution: Key Management and Authentication Protocol Overview



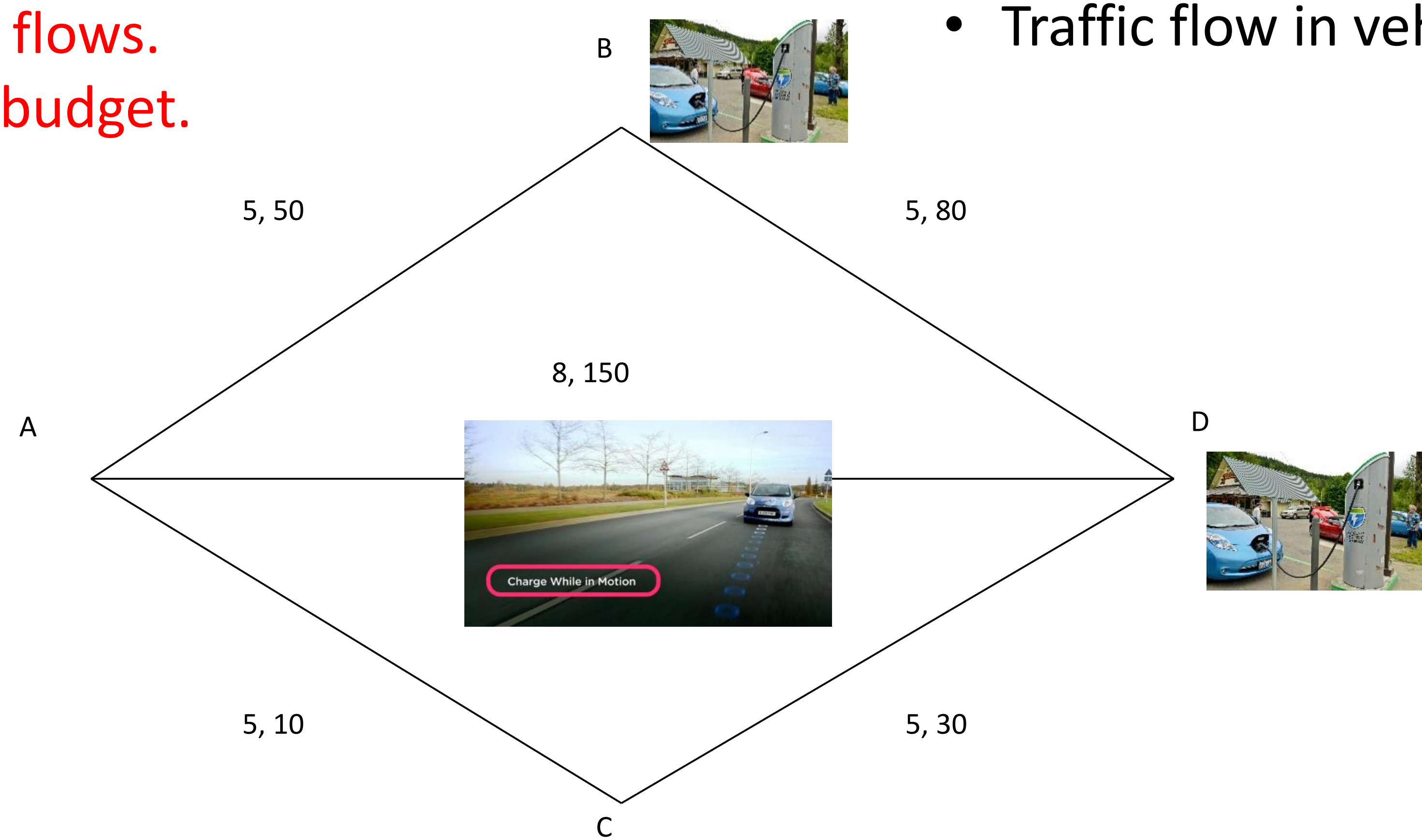
Li, Nahrstedt, Smartgridcom'14

Impact on Power Grid Informatics - Representation

Problem : Find optimal locations for charging facilities to serve the most traffic flows.
Constraint: budget.

Link information:

- Length in unit
- Traffic flow in veh/hr



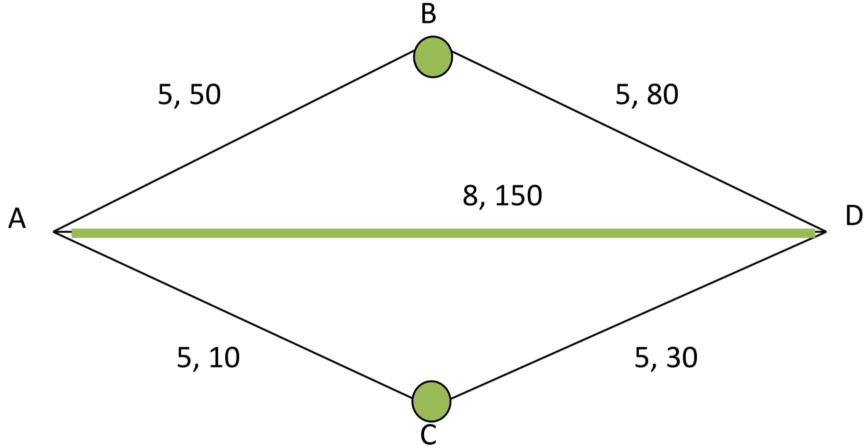
Change, Li, Nahrstedt, IEEEE IEVC’14

Approximation Solution

- We follow steps:
  1. Pick candidate paths to assign only charging pads.
  2. Make rest of the nodes candidate sites to assign charging stations. Note: pads and stations cannot overlap.
  3. Optimize which path(s) to assign charging pads and which node(s) to assign charging stations.

To locate:

- 1 charging pad
- 1 charging station



Conclusion

- This community plans for 2050
  - Tremendous engineering and scientific problems need to be solved until 2050
    - Wireless charging, new materials, heterogeneity, …
- EVs, Power Grid, Roads are all becoming cyber-physical systems
- Information will be acquired, stored and processed leading to
  - Big Data problems (volume, velocity, variety, value, visualization…)
  - Information Representation and Integration problems (many stakeholders)
- Information will be communicated in trustworthy manner leading to
  - Security and privacy problems (access control, authentication, ..)
  - Information Reachability problems due to mobility
  - Heterogeneous communication problems (latency, losses, …)
  - Integrated social, vehicular and road network problems

Backup Slides

OPTIMAL PLACEMENT OF CHARGING STATIONS AND DYNAMIC WIRELESS CHARGING PADS (CHANG, LI, NAHRSTEDT)

Objective

- Charging facilities:
  - Charging station

  - Dynamic Wireless Charging pad

- Find optimal locations for charging pad and station
  - Intersection/node: station
  - Road/link: pad

Sample Network

Goal: find optimal locations for charging facilities to serve the most traffic flows.
Constraint: budget.

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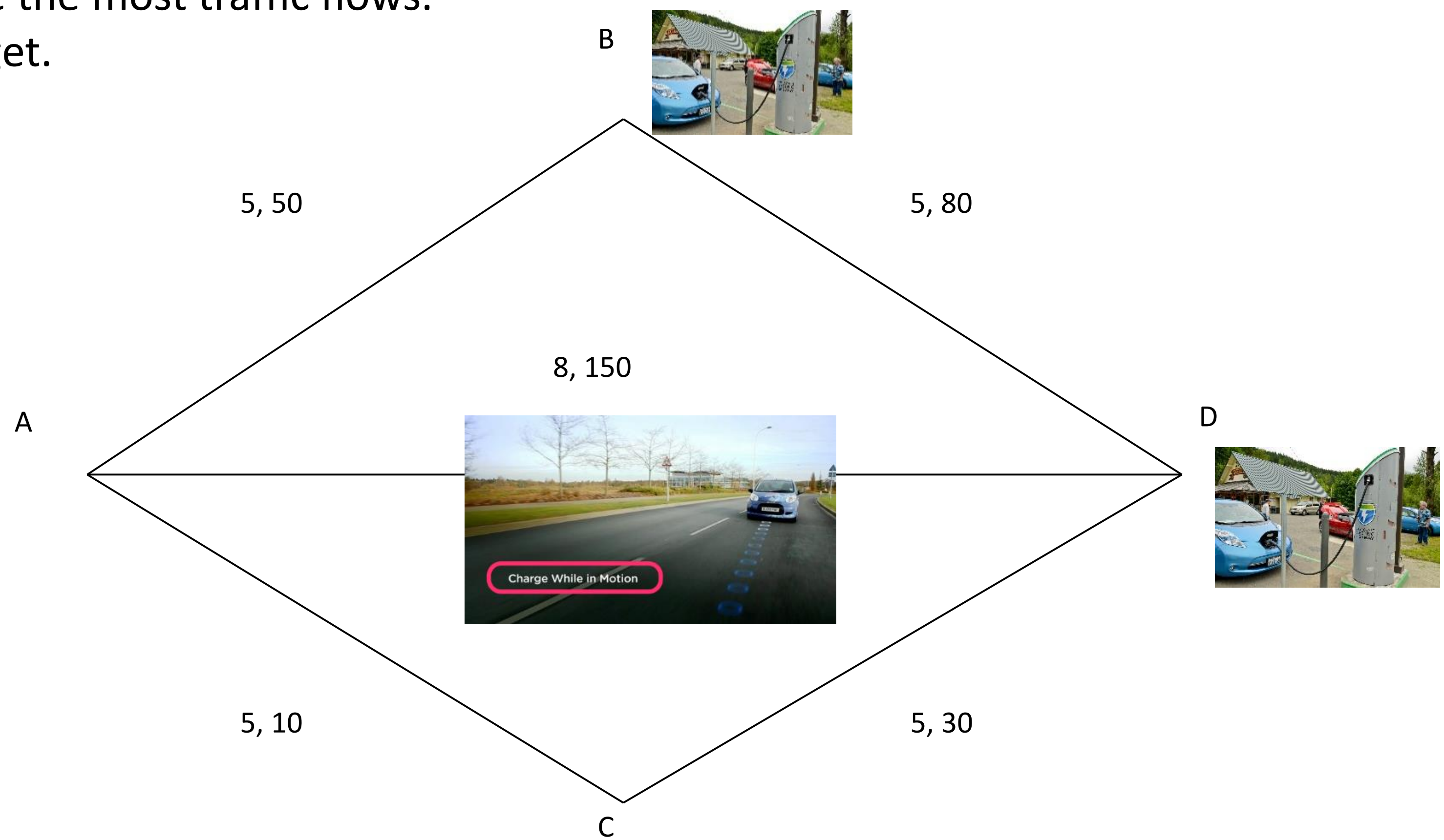


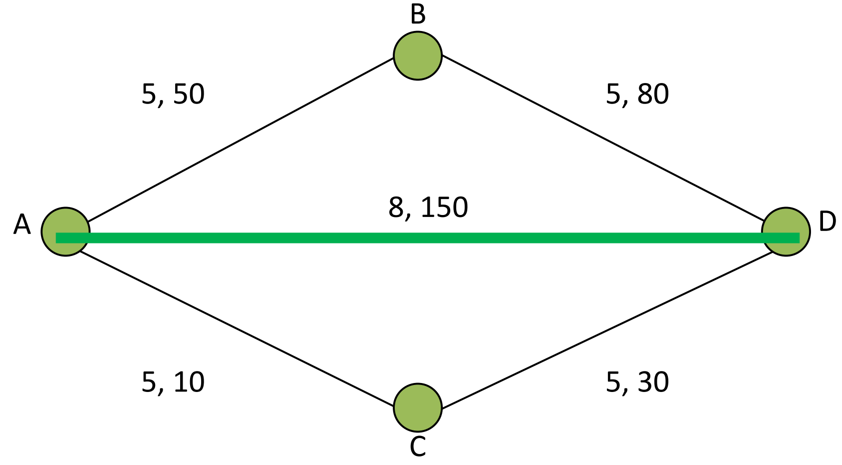
Flow Refueling Location Model (FRLM)

- Proposed by M. Kuby in 2005
- Major features:
  - Assume vehicles travel on pre-planned routes.
  - Consider EV driving range
  - Allow EVs to refuel multiple times while driving

Candidate Combination

A candidate combination is a set of candidate locations (nodes & links).

- Candidate combination 1: {A, C, D}
- Candidate combination 2: {B, AD}

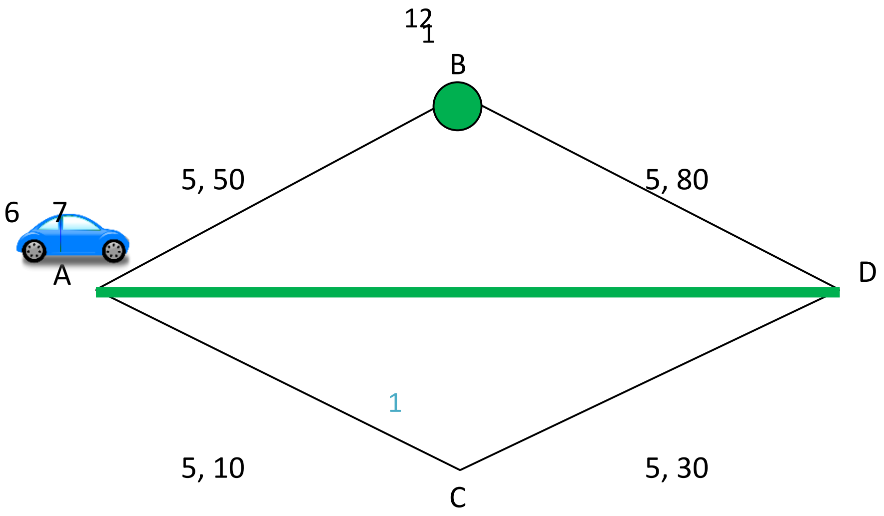


Eligible Combination

- An eligible combination of an OD pair is a candidate combination which could ensure an EV to complete a round trip from O to D.

- State of Charge (SOC). E.g. 6 unit.

- Candidate combination: {B, AD}
  - {B, AD} is an eligible combination of Flow AB.
  - {B, AD} is not an eligible combination of Flow AC.



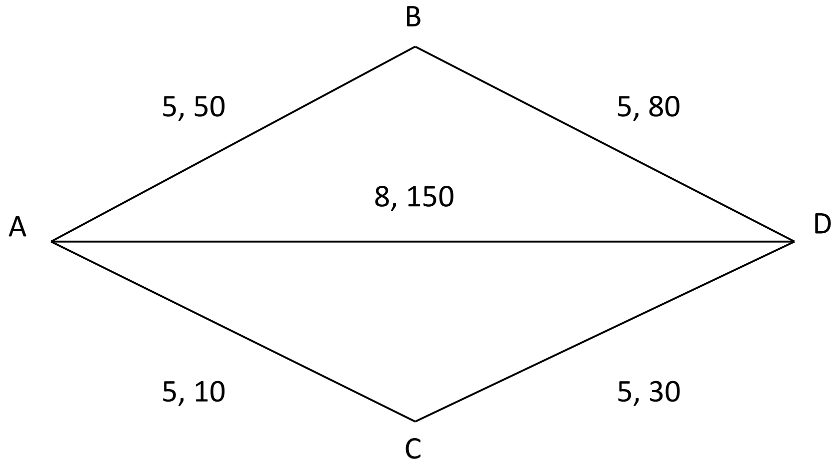
Challenge

- # combinations = $\binom{4}{1} * \binom{5}{1}$ 1 station, 1 pad

  # combinations = $\binom{4}{2} * \binom{5}{1}$ 2 station, 1 pad

  # combinations = $\binom{4}{3} * \binom{5}{1}$ 3 station, 1 pad

  …



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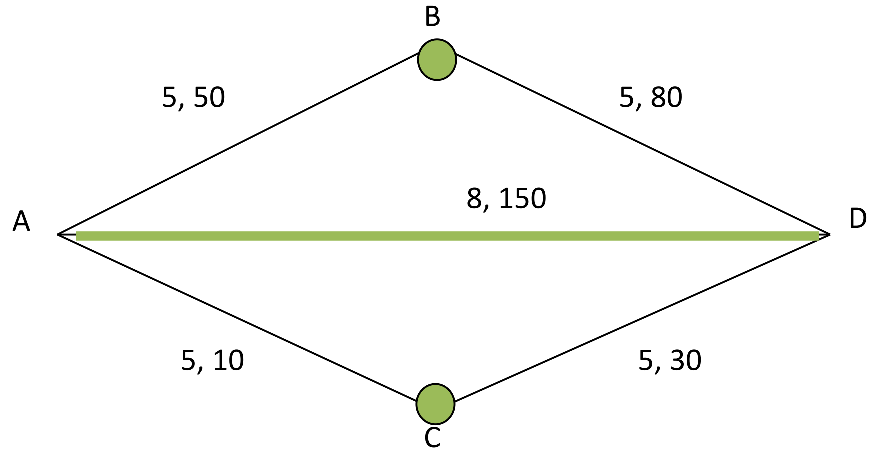
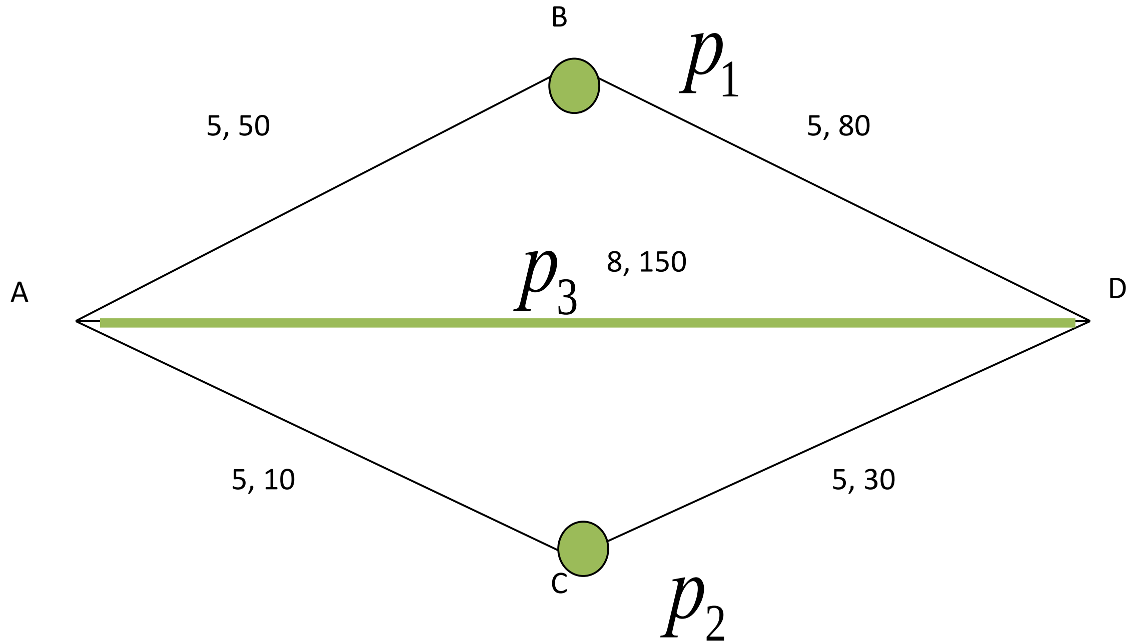


Sample Network

Goal:

To locate: 1 Charging station, 1 Charging pad

On: 1 Candidate link p_3,2 Candidate nodes p_1, p_2



Coefficient matrix

a_{hp}

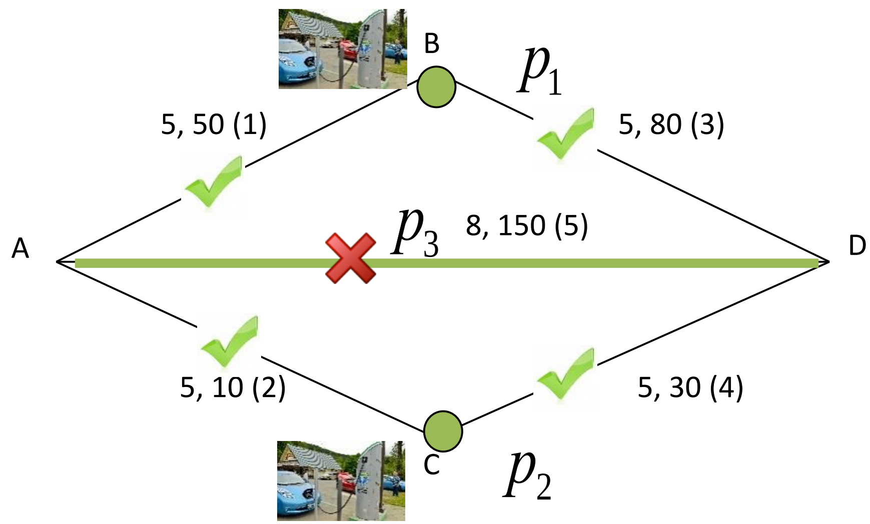
Candidate location

Combination	p_1	p_2	p_3
h_1	1	1	0
h_2	1	0	1
h_3	0	1	1

b_{qh}

Combination

Flow	h_1	h_2	h_3
q_1	1	1	0
q_2	1	0	1
q_3	1	1	0
q_4	1	0	1
q_5	0	1	1



Combination 1 (h_1 170veh/hr
Combination 2 (h_2 280veh/hr
Combination 3 (h_3 190veh/hr

Optimization problem formulation

$$\text{maximize } Z = \sum_q f_q^T x_q$$

Maximize the flows being refueled

$$\text{s.t.} \sum_{h \in H} b_{qh} v_h \geq x_q, \ \forall q \in Q$$

A flow is captured if at least one eligible combination is open

$$a_{hp} y_p \geq v_h, \ \forall h \in H, \forall p \in P$$

A combination is open if all facilities required by the combination are open

$$\sum_{p \in P} y_p = c,$$

Fix the number of charging facilities to locate

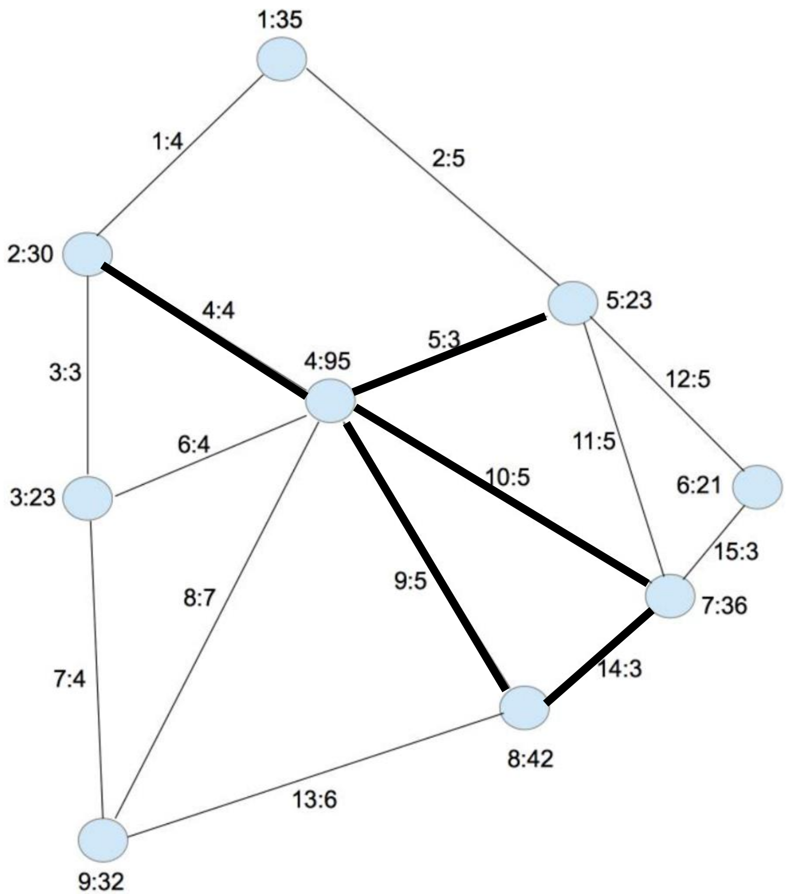
$$y_{p_n} + y_{p_r} \leq 1, \ \forall p_n \in p_r, \forall p_n \in P, \forall p_r \in P$$

No overlap of stations and pads

$$x_q, y_p, v_h \in \{0, 1\}, \ \forall q, \forall h, \forall p$$

Binary variables

Evaluation

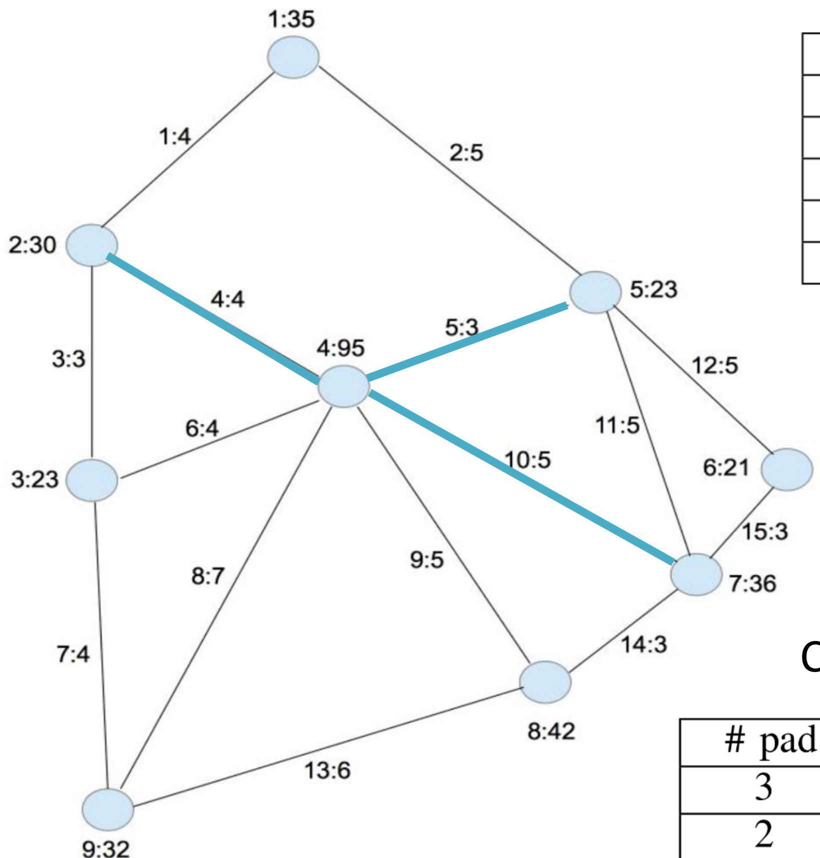


TOP FLOWS OF THE NINE NODE NETWORK

Flow ID	O	D	Distance	Path	Volume (veh/hr)
25	4	8	5	$4 \rightarrow 8$	1197
22	4	5	3	$4 \rightarrow 5$	1092.5
10	2	4	4	$2 \rightarrow 4$	1068.8
24	4	7	5	$4 \rightarrow 7$	1026
34	7	8	3	$7 \rightarrow 8$	756

Find optimal locations for 3 charging facilities

Facility Allocation



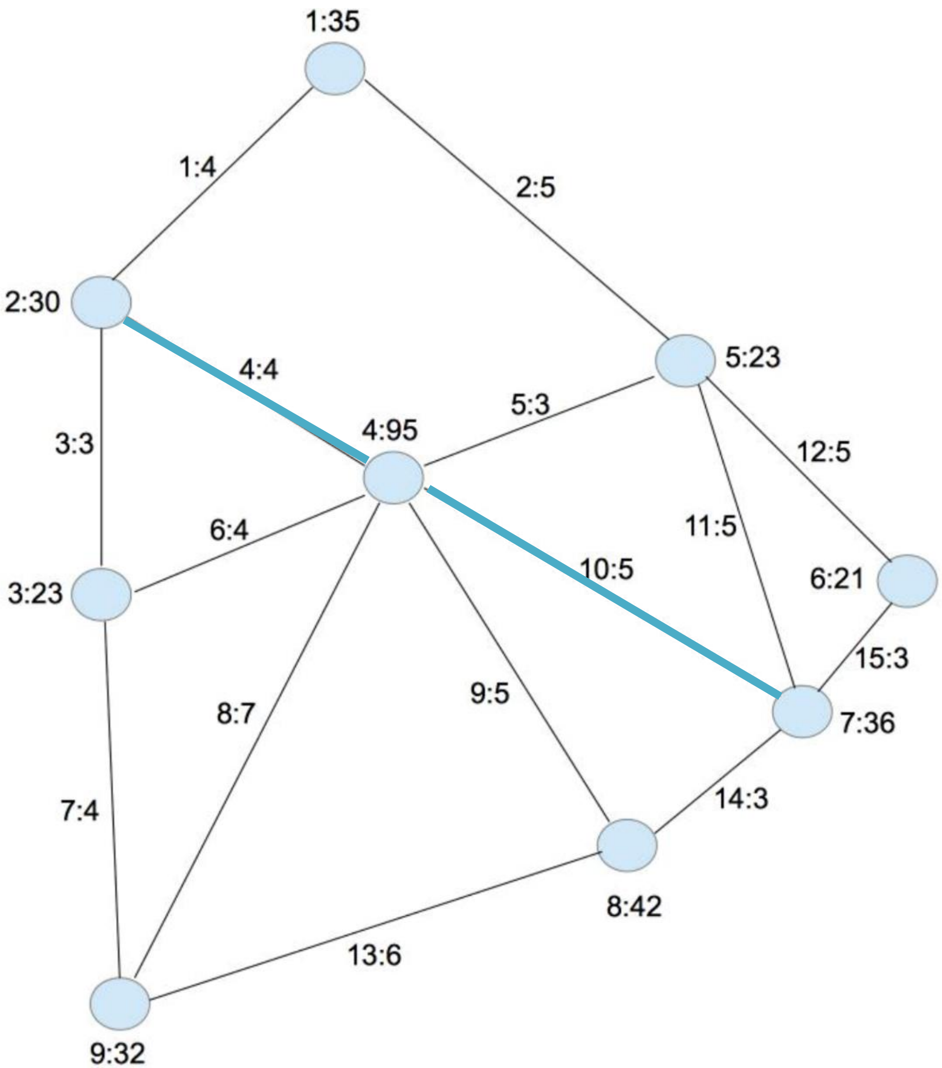
Charged Traffic flows

Flow ID	O	D	Distance	Path	Volume (veh/hr)
10	2	4	4	$2 \rightarrow 4$	1068.8
11	2	5	7	$2 \rightarrow 4 \rightarrow 5$	147.86
13	2	7	9	$2 \rightarrow 4 \rightarrow 7$	180
22	4	5	3	$4 \rightarrow 5$	1092.5
24	4	7	5	$4 \rightarrow 7$	1026

Charged Traffic flows with different combinations

# pad	# station	Configuration	Volume (veh/hr)
3	0	Link 4, Link 5, Link 10	3515.1
2	1	Link 4, Link 5, Node 1	2309.1
1	2	Node 1, Node 2, Link 5	2726.9
0	3	Node 1, Node 2, Node 4	1692.2

Charging time required



Nissan Leaf

Node 2 ➔Node 7, 252mile.
Speed limit 70mile/hr.
Requires 3.6 hours to complete the trip.

Charging station: 24hrs of charging.

Charging pad: does not need to stop for charging.

Summary

- Goal: final optimal locations for charging facilities including **charging stations** and **charging pads**.
- Extended the FRLM model.
- Locating charging pads:
  - Serve more traffic flow
  - Save charging time

Topic Slide

- Main Point
  - – Sub-point
    - next point
      - – and yet another point
        - » oh … and don’t forget this important point!!