CSE595 Topics in Convergence Research

Model Checking for Smart Grids

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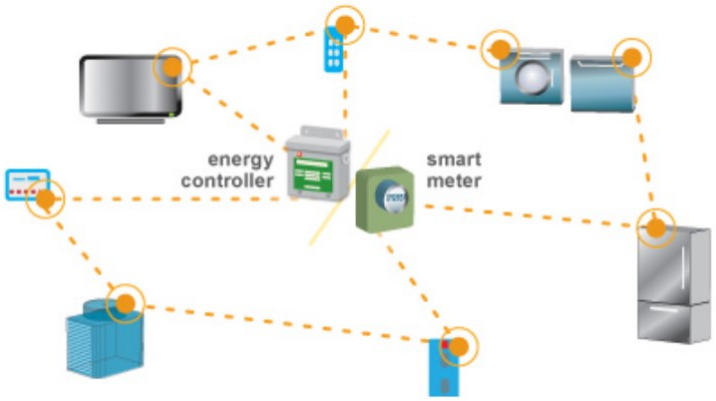
Smart Grid System

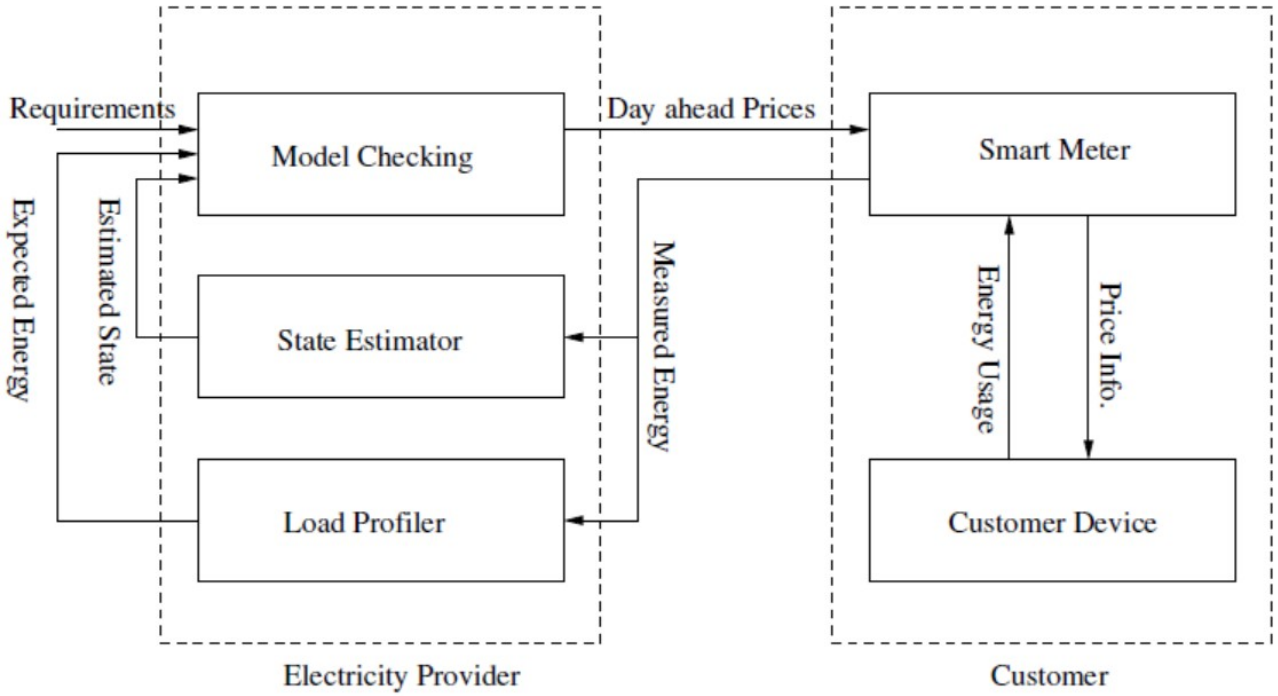
- Control the electricity demand by pricing
- Smart meters
  - Enable two way communications between electricity providers and customers
  - Post electricity price
  - Report energy consumption level



Smart Grid System

- Real-time pricing
  - Electricity price is computed real-time based on the current load
  - Can control the demand efficiently
- Day-ahead pricing
  - Price schedules for a day is announced before the day
  - No uncertainty about electricity prices
  - Some tasks are not interruptible (e.g. laundry)

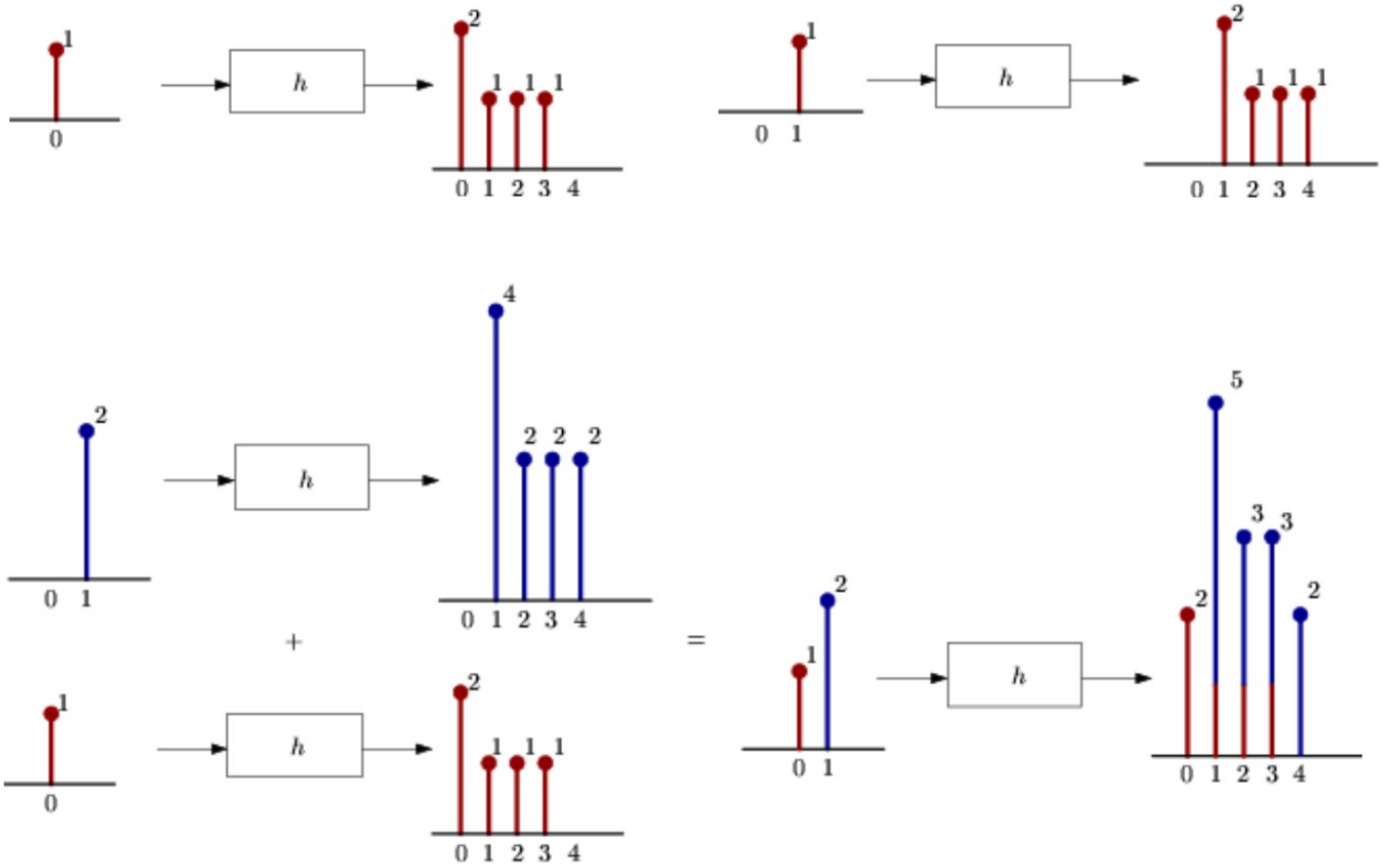
Smart Grid System



Linear System Model

- Superposition principle
  - $F(a \cdot x + b \cdot y) = a \cdot F(x) + b \cdot F(y)$

Linear Time Invariant System Model



Specification on Linear System Model

- Let x: Nat $\rightarrow$ Real and y: Nat $\rightarrow$ Real be outputs of an LTI system.

  - `y > 1`
  - `X y > 10`
  - `[] y < 200`
  - `<> y > 100`
  - `x > 2 U y > 10`
  - `<> [] ( 10 < y /\ y < 20 )`

Smart Grid System Model

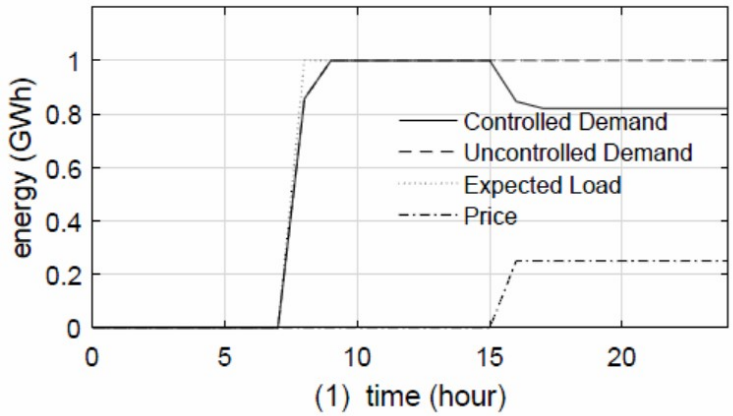
- The change of electricity demand is
  - Proportional to the difference between the expected load and the current load
  - Negatively proportional to the electricity price change

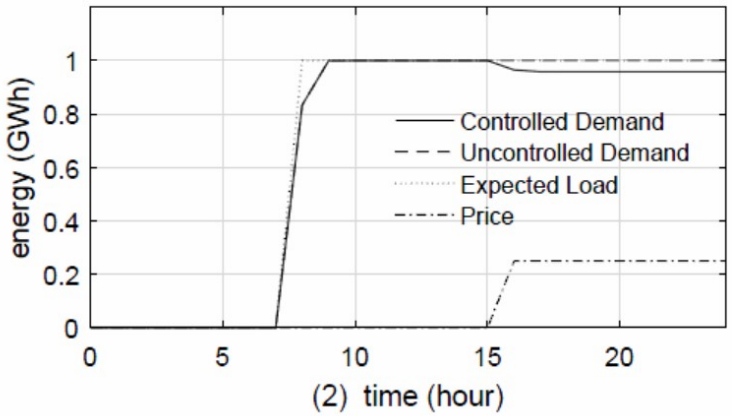
$$\dot{e}(t) = a \cdot (\ell(t) - e(t)) - b \cdot p(t)$$

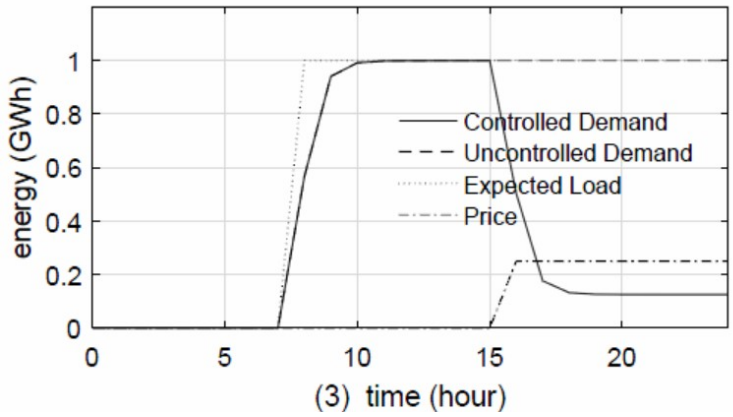
Smart Grid System Model

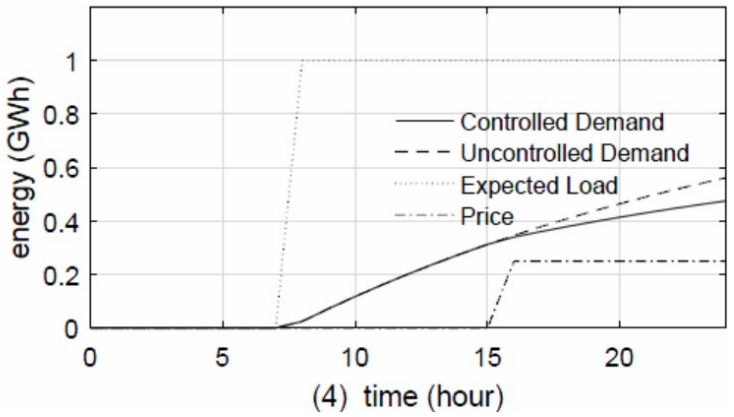
- Some representative types of loads
  - Sensitivity to the difference between expected loads and the current load
    - (+) TV, Heater
    - (-) Refrigerator, Vacuum machine
  - Sensitivity to the price
    - (+) Laundry machine, Vacuum machine, TV
    - (-) Heater, Refrigerator

Smart Grid System Model









Demand Changes in response to expected load and price changes

Requirements on Smart Grid Systems

- The total energy demand of all devices should never exceed 1.65 GWh
- The price changes are always within ± 0.1 \$/KWh range of the nominal value
- The accumulated price changes for a day never exceed ± 0.1 \$/KWh
- The accumulated demand of each device type is within ± 0.5 GWh range of the accumulated expected load of the device for the day

Model Description

```
model:
var    # energy and accumulated energy demand
  ext:state, et:output, Ext:state, Et:output,
  exh:state, eh:output, Exh:state, Eh:output,
  exv:state, ev:output, Exv:state, Ev:output,
  exf:state, ef:output, Exf:state, Ef:output,

  # total demand of all devices:et + eh + ev + ef
  e: output,

  # expected load , acc. expected load
  lt: input,  lh: input,  lv: input,  lf: input,
  Lxt: state, Lxh: state, Lxv: state, Lxf: state,
  Lt: output, Lh: output, Lv: output, Lf: otuput,

  # price change, acc. price change
  p: input, Px: state, P: output,

  # clock and tick
  c: state, dc: input;
```

```
mode
  M = {
  # individual device's energy demand
  ext = 0.0009*ext + 0.1426*lt - 0.1019*p,
  exh = 0.0025*exh + 0.1658*lh - 0.0276*p,
  exv = 0.1353*exv + 0.3738*lv - 1.3084*p,
  exf = 0.9512*exf + 0.0476*lf - 0.0476*p,
  et  =        ext + 0.8573*lt - 0.6123*p,
  eh  =        exh + 0.8337*lh - 0.1390*p,
  ev  =        exv + 0.5677*lv - 1.9868*p,
  ef  =        exf + 0.0246*lf - 0.0246*p,

  # total energy demand of all devices
  e = ext + exh + exv + exf
    + 0.8573*lt + 0.8337*lh + 0.5677*lv
    + 0.0246*lf - 2.7627*p,

  # accumulated energy demand
  Ext = Ext + 0.1427*ext + 0.9796*lt - 0.6997*p,
  Exh = Exh + 0.1663*exh + 0.9724*lh - 0.1621*p,
  Exv = Exv + 0.4323*exv + 0.8131*lv - 2.8458*p,
  Exf = Exf + 0.9754*exf + 0.0486*lf - 0.0486*p,
```

```
  Et  = Ext + 0.3775*lt  - 0.2697*p,
  Eh  = Exh + 0.3610*lh  - 0.0602*p,
  Ev  = Exv + 0.2162*lv  - 0.7566*p,
  Ef  = Exf + 0.0082*lf  - 0.0082*p,

  # accumulated expected energy
  Lxt = Lxt + lt,    Lt = Lxt + 0.5*lt,
  Lxh = Lxh + lh,    Lh = Lxh + 0.5*lh,
  Lxv = Lxv + lv,    Lv = Lxv + 0.5*lv,
  Lxf = Lxf + lf,    Lf = Lxf + 0.5*lf,

  # accumulated price change
  Px = Px + p,       P = Px + 0.5*p,

  # clock
  c = c + dc
  };
```

Specification Description

```
specification:
condition
 # Initial conditions
 Init=(Ext=0 /\ Exh=0 /\ Exv=0 /\ Exf=0 /\
       Lxt=0 /\ Lxh=0 /\ Lxv=0 /\ Lxf=0 /\
       ext=0.01 /\ exh=0.12 /\ exv=0 /\ exf=0.44 /\
       Px=0 /\ c=0),

 # Final conditions
 Final=(
   # accumulated energy demand of each device should
   # be close to its expected accumulated energy
   Lt - 0.5 <= Et /\ Et <= Lt + 0.5 /\
   Lh - 0.5 <= Eh /\ Eh <= Lh + 0.5 /\
   Lv - 0.5 <= Ev /\ Ev <= Lv + 0.5 /\
   Lf - 0.5 <= Ef /\ Ef <= Lf + 0.5 /\
   # Bound for acc. price change
   -0.1 <= P /\ P <= 0.1),

 # Always enforced conditions
 Safety=(
  # total energy demand should be less than 1.65 GWh
  e <= 1.65 /\
  # price change should be within +- 0.1 $/KWh range
  -0.1 <= p /\ p <= 0.1 /\
  # positive energy demand and dc
  et >= 0 /\ eh >= 0 /\ ev >= 0 /\ ef >= 0 /\
  dc = 1.0),

 # Expected load for the day
 Load=Init /\
   lt = 0.10 /\ lh = 0.70 /\ lv = 0.00 /\ lf = 0.40 /\
 X(lt = 0.00 /\ lh = 0.70 /\ lv = 0.00 /\ lf = 0.40 /\
 X(lt = 0.00 /\ lh = 0.70 /\ lv = 0.00 /\ lf = 0.40 /\
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 X(lt = 0.10 /\ lh = 0.70 /\ lv = 0.00 /\ lf = 0.40 /\
   Final  /\  Safety
 ))))) ))))) ))))) ))))) ))))),

# The final goal: initial, final, expected load for
#                 the day, and safety conditions
Goal = (
        Load /\
        (Safety U (c >= 24)) );
```
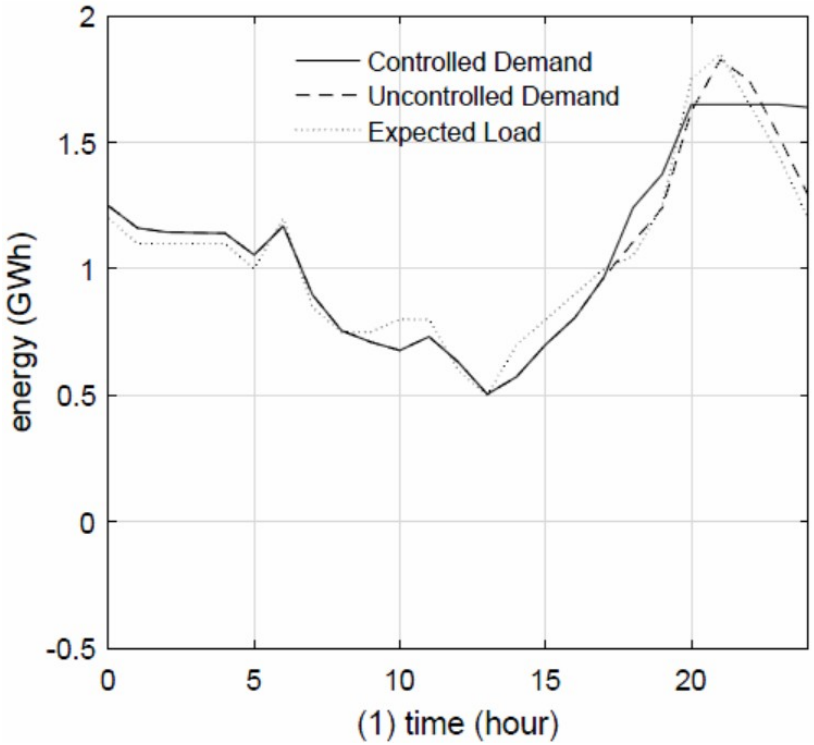
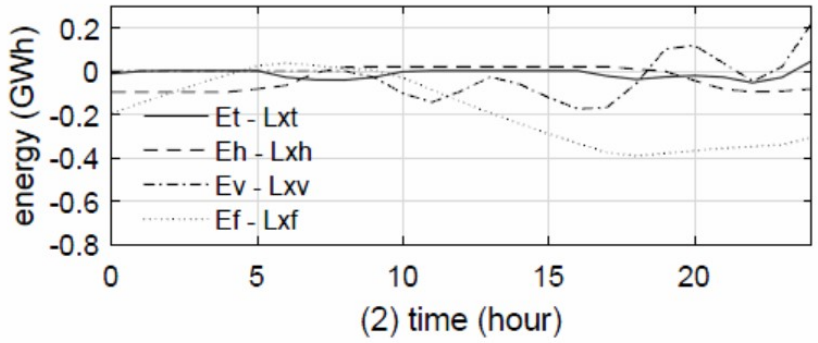
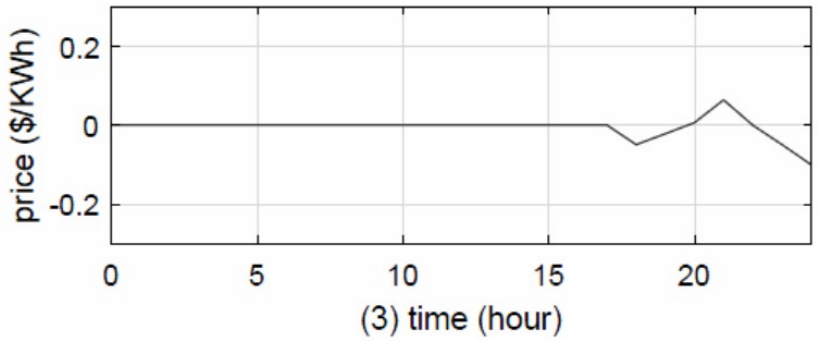

Model Checking Results

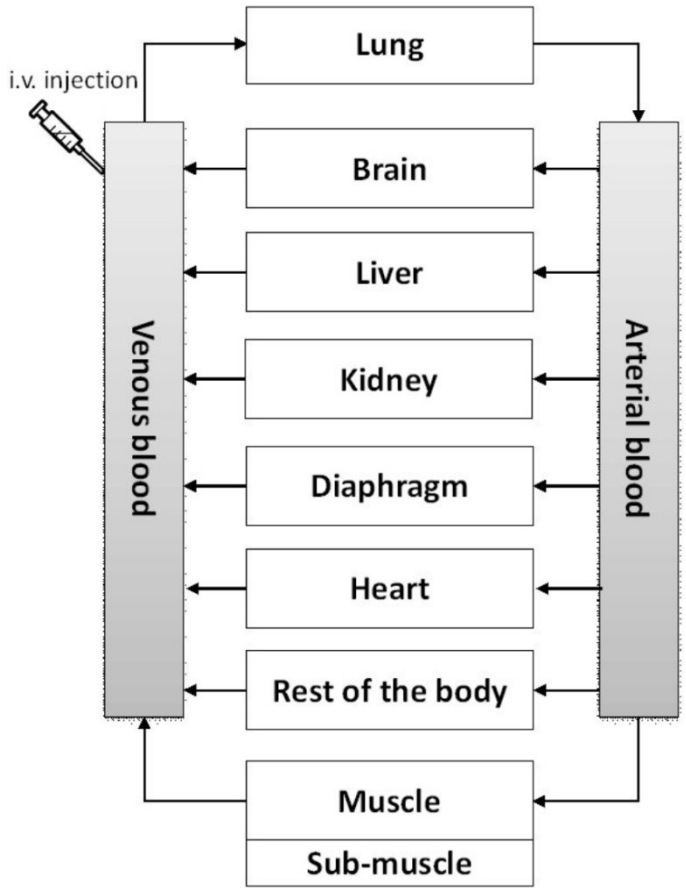






Pharmacokinetic Model

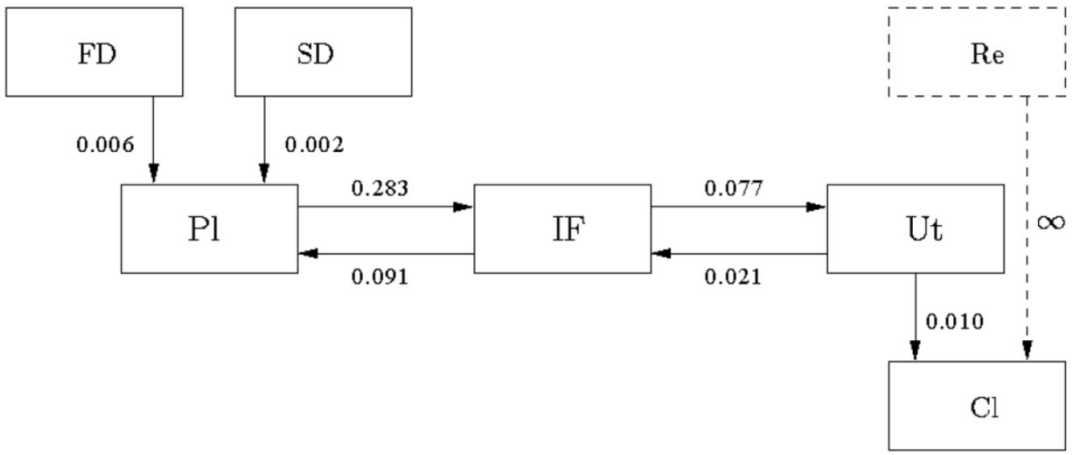
- Drug Kinetics (ADME)
  - Absorption
  - Distribution
  - Metabolism
  - Excretion



Perfusion model

Pharmacokinetic Model

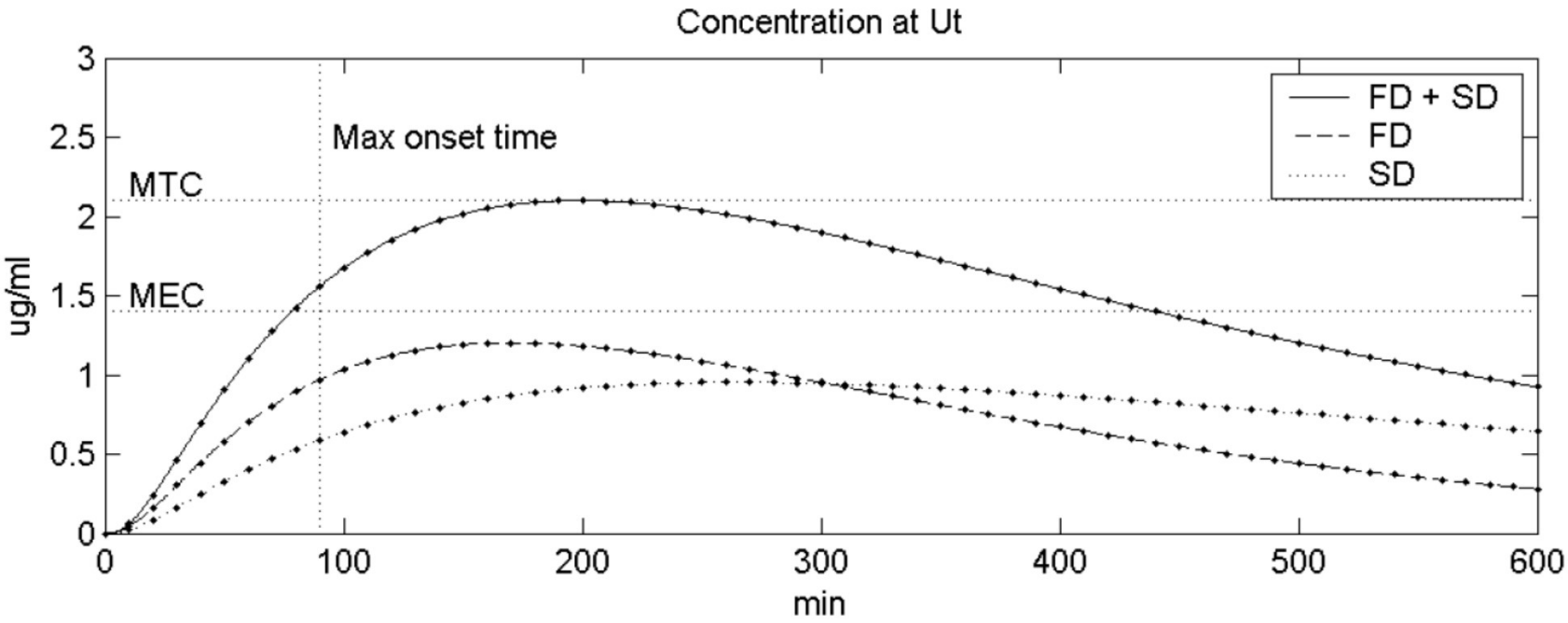
- Compartment model
  - Drug molecules are moving from one compartment to other compartments
  - The rate of drugs leaving a compartment is proportional to the amount of drug in the compartment
  - Drug kinetics can be modeled as a Markov chain
    - Each compartment corresponds to a state
    - Drug transition rates correspond to probability transition rates



Requirements for a Prescription

- The onset time is no later that 1.5 hours (sampling time is 10 min)
- The active duration is at least 6 hours
  - The minimum effective concentration level (mec) is 1.4 ug/ml
- The drug concentration should never exceed the toxic limit
  - The minimum toxic concentration level (mtc) is 2.1 ug/ml

Model Checking Results



Model Checking Results