Market Mechanisms for Decentralized Control and Allocation of Energy

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Problem Domain

- Decentralized decision making
- Economic and environmental optimization
  - Decentralized logistics
  - Market design and analysis
- Local decision makers
  - Limited information
  - Adaptive to their dynamic environment
  - Repeated decisions
  - Learning from past

- Presentation of research project activities and results
  - DEAL project (completed)
  - Electricity Networks (starting)
  - Research trajectories similar

Areas

- Application and modeling areas
  - Decentralized logistics
    - Multiple parties
    - Limited information
    - Local decisions

  - Energy markets
    - Decentralized suppliers and decisions
    - Market-based distribution

Economic optimization in dynamic settings

- Problem types
  - Economic games
    - Negotiation, auctions, oligopoly games (cournot)
  - Logistic optimization problems
    - Routing, inventory management, scheduling
- Goals
  - Design of adaptive strategies in games
    - Adaptive software agents
    - Computational Intelligence (CI) techniques
  - Design of adaptive solutions for optimization
    - CI techniques
    - Market mechanisms (games for allocation)
  - Market / game design and analysis
    - Market rules (game rules)

DEAL: Cargo Acquisition Online

- Distributed Engine for Advanced Logistics (DEAL)
    - CWI, Almende, Vos Logistics, Post-Kogeko, EUR, VU, RU, Groenevelt
- Dutch Governmental E.E.T. funding program:

  Energy, Ecology, and Technology

- Half of the trucks on the road is empty…
    - Waste of energy
    - Environmental pollution
- Can efficiency be increased?

Transportation

- Transportation (road, air,..)
    - Spot markets
        - Auctions on internet emerging
            - bidfreight.com, freight-traders.com, ..

Case 1

- Case 1

Online auctions for cargo for transportation by trucks
(DEAL fundamental research)

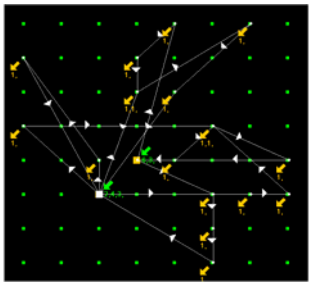
DEAL: Agents and Trucks

- Online auctions and negotiations for cargo
  - Agents buy cargo for the trucks
    - Depots with cargo
    - Electronic spot markets: Auctions
  - Transport companies (carrier)
    - Own trucks

  - During the day, cargo can be “bought” by agents while trucks are on the move.
    - Every truck has its own agent (e.g.)
    - Optimize the usage of transport capacity of a truck
      - Load capacity
      - Load combinations
      - Dynamic routing

Agent Strategies

- Bidding and negotiation strategies for truck agents
  - What is the value of specific cargo for the truck?
    - Dynamic routing and bundling problems
  - What are good values to bid
    - Adaptive
      - Competitors, market dynamics
  - How can this be decentralized
    - Market-based allocation
      - Experiments / simulation
      - Prototypes

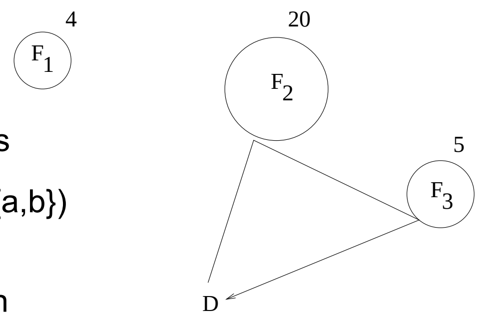


Anticipating Future Cargo

- Anticipating future cargo (prediction) improves agent's position
  - Combining loads
    - Bidding
    - Routing

Bidding: Fruitful Regions

- Combining loads
- A sequence of loads from fruitful regions is auctioned one by one
  - “Randomly”
  - Combinatorial auctions not applicable



- Strong complementarities

  Val({a})+Val({b}) < Val({a,b})

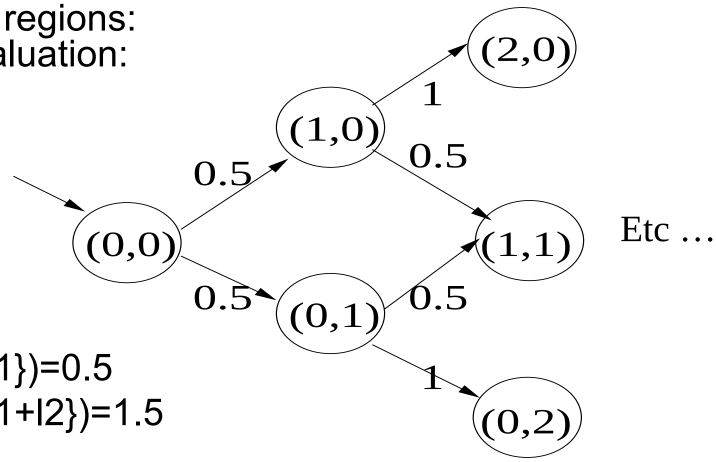
- Anticipating future cargo improves agent’s position

Each Truck

- How to bid for the current item?
- Capacitated
  - capacity per truck (5 units)
  - State representation in terms of loads per Fruitful Region

State Representation

- For 2 regions:
  net valuation:

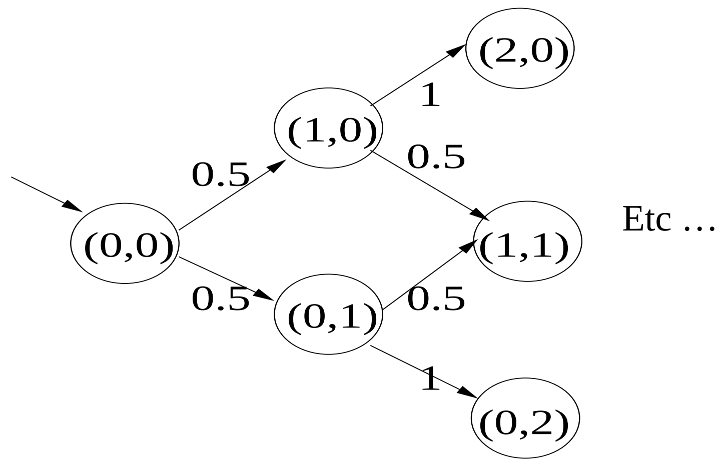


- Val({I1})=0.5
- Val({I1+I2})=1.5
- …..

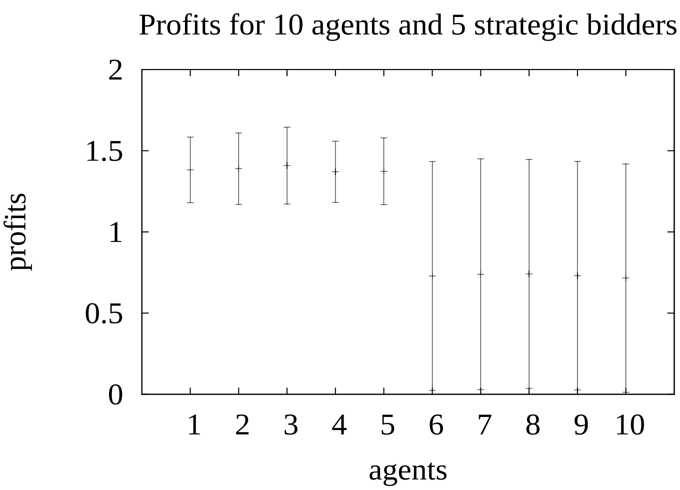
Policy

- Idea:
- Each transition from state S to S':
  Policy with three possible strategies:
  1. Straightforward - true valuation
  2. Overbid
  3. Underbid
- Each transition from state S to S' adorned with three values P_i (i=1..3)
- Learn the values P_i (i=1..3) per state
  - Monte Carlo-like approach:
    - History of choices per state transition is maintained
    - Assigned credit proportional with difference to average utility

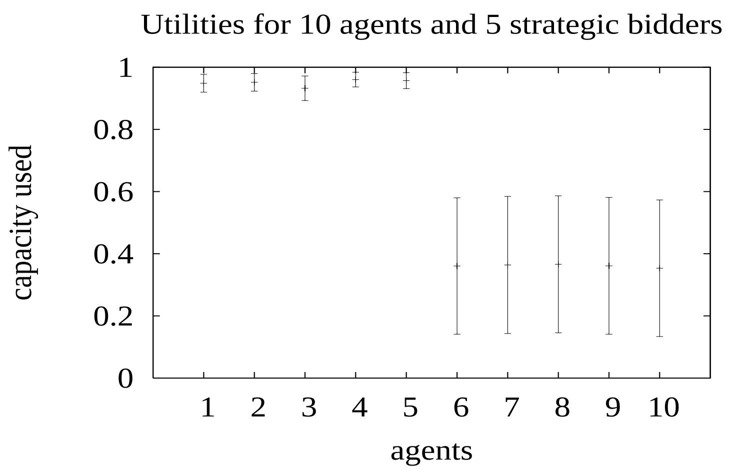
State Representation



5 versus 5



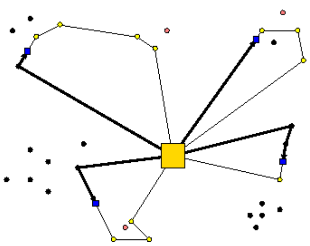
Capacity Used



Routing: Cargo Transportation Online

- Online announcements of new cargo
  - Acquire cargo for the trucks
    - While vehicles are driving

- Routing efficiency can be improved if announcement times of future loads were *known*.



Approach

- Designing *adaptive strategies*
  - Logistic strategies in online optimization
    - Online pick-up
    - Not hard-coded decisions, but rules and decision functions
- Learning
  - Evolutionary Algorithms (EA)
    - Strategies evaluated by simulation
- Forecasting
  - Exogenous
    - Fixed or changing demand distribution
  - Interactive
    - E.g. satisfied customers
- Substantially improved performance
  - Computer experiments
  - Benchmarked

Case: Conclusion

- Learning yields profitable bidding
  - Complementarities between items (loads)
    - Smart combination and anticipation
  - Forecasting / learning
  - Less distance travelled and energy used
  - Possible reduction of number of trucks
  - ….

Case 2

- Case 2

  Online auctions for cargo for transportation by trucks: Interactive Demonstrator / Prototype (DEAL applied research)

Demonstrator

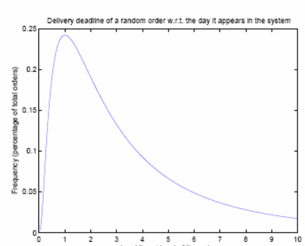
- Demonstrator
  - For and with VOS Logistics
    - Top 5 European transportation company
- Goals: Platform for
  - Feasibility of auction-based system for *outsourcing*
  - Increase flexibility and efficiency of planning
  - Test distributed decision making with auctions
  - Test automated trading strategies for agents
  - Test the behavior of human planners

Settings

- Case for transportation
  - Depot in the Netherlands
    - Delivered all over Germany
    - And the other way around ("return orders")
  - Based on real data
    - Order distributions derived from these
  - VOS as 4PL organizer
    - Outsourcing of loads to carriers
  - Human players
    - n with role of carrier
      - Carrier has k trucks
    - 1 with role of VOS
  - Agent players
    - Many to simulate the market of carriers

Settings

- Loads
  - With delivery deadlines
    - Adapted lognormal-like distributions
    - 1 - 2 days to a week
  - Auctions sequentially
    - Short lead time: 1 – 2 days
      - English auctions
      - Closes 1 hour after "last" offer
    - Longer lead time: > 3 days
      - Too early for most planners
      - Reservation threshold
        - » Reasonable max. bid price
      - An order below threshold starts aucti
      - If 2 days in advance: auction starts
- Various parameters
  - Give e.g. market saturation
  - Pre-filled trucks

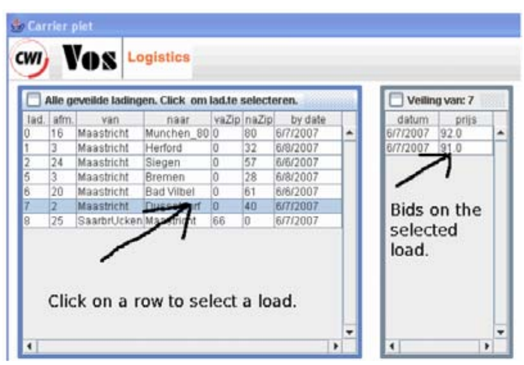


Automated Bidders

- Role automated bidding agents
  - Stability of the market
  - Pricing converge to realistic levels
- Settings
  - Simple, myopic bidding strategies
    - Based on standard industry price table
      - Above and below
    - Normal distributions
      - Initial bids
      - Reservations values
    - Parametrized
      - Percentages

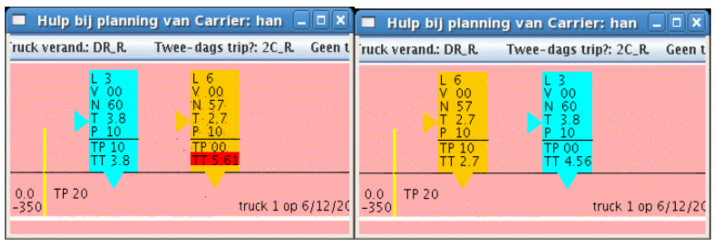
Demonstrator System

- Two windows
  - Visualizing auctions in progress
    - Loads, bids



Demonstrator System

- Planning assistance window for human planners
  - Visualization of order planning
    - Fill-level of trucks
  - Incorporation of new orders in these
    - Insertion heuristics
  - Cost calculation for given plans (realistic)
    - Fixed cost per truck per day
    - Variable costs proportional to traveled distance



Case Study with Demonstrator

- At VOS Logistics
    - 5 experienced human planners
- Conclusions (preliminary)
  - Faithfulness of platform and behavior
  - Platform showed
    - Importance of competition for profit
    - Complexity of planning in competitive logistics
    - Combination of these!
    - Possibilities for testing agent strategies and software
  - Further extensions
- Base for commercially auction-based allocation platform in logistics

Case Study with Demonstrator

- Demonstration…

Conclusion

- Market-based approaches allow for efficient solutions with proper support
    - Environmental: CO_2 and energy usage reduction
    - Commercial
  - Especially
    - Decommitment
    - Anticipation
    - Decision support
    - Proper auction types

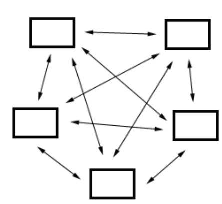
Case 3

- Case 3

  Pricing and Market Mechanisms for Electricity Networks
  (First modeling and demonstration results; young research)

Electricity Networks

- Intelligent management of distribution
  - By (additional) voltage control and
  - By automatic optimization
    - Centralized / decentralized
- Important aspects and objectives
  - Stability (tripping)
  - Dynamic demand and supply
  - Efficiency (losses, CO2-emission)
  - Aging
- Distributed power generation
  - Large and small power generators
- Intermediate voltage network



Electricity Networks

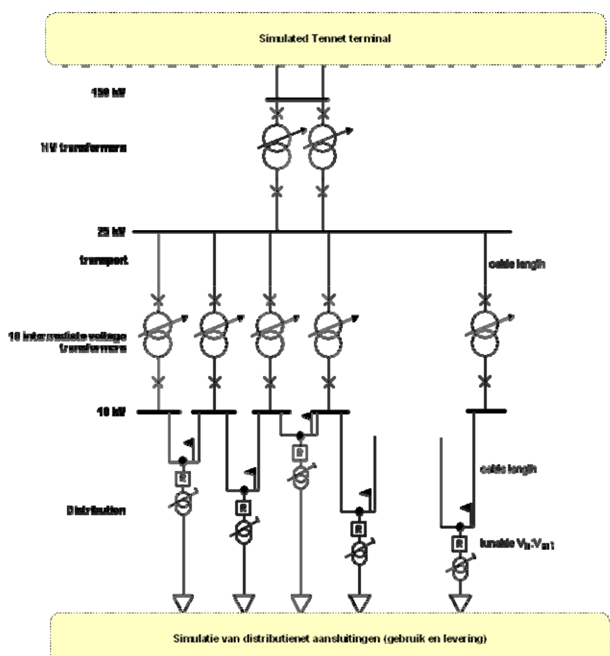
- ESTP demonstrator project: first, basic models, demonstrators, and experiments
  - CWI
  - DySI
  - LOFAR
  - KEMA
  - dynamic modeling for stable operation of intermediate network
- First models/solutions/demonstrators
      - decentralized optimization, w.r.t. consumers/prosumer dynamics
  - First-phase project
    - Starting phase of long-term research activities
    - Feasibility
    - Demonstration with simple models

Positioning

- Focus:
  - Decentralized, market-based pricing for electricity networks
  - Intermediate voltage network
  - Simulation of networks
  - Distributed power generation

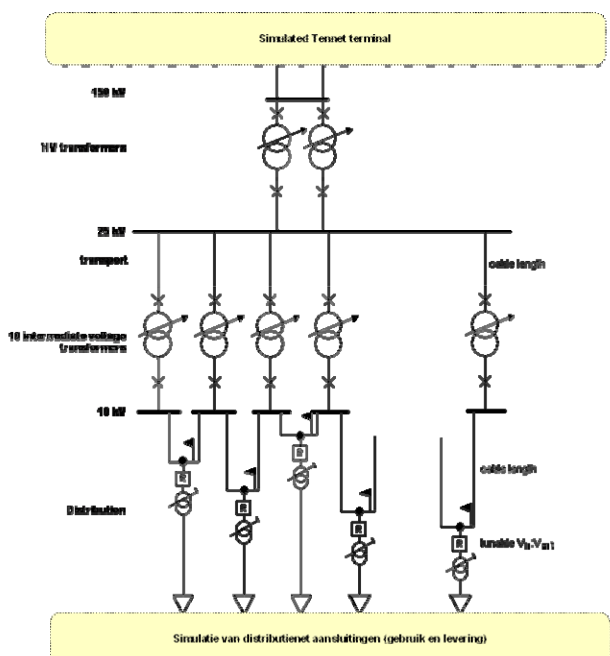
Simulation and Control

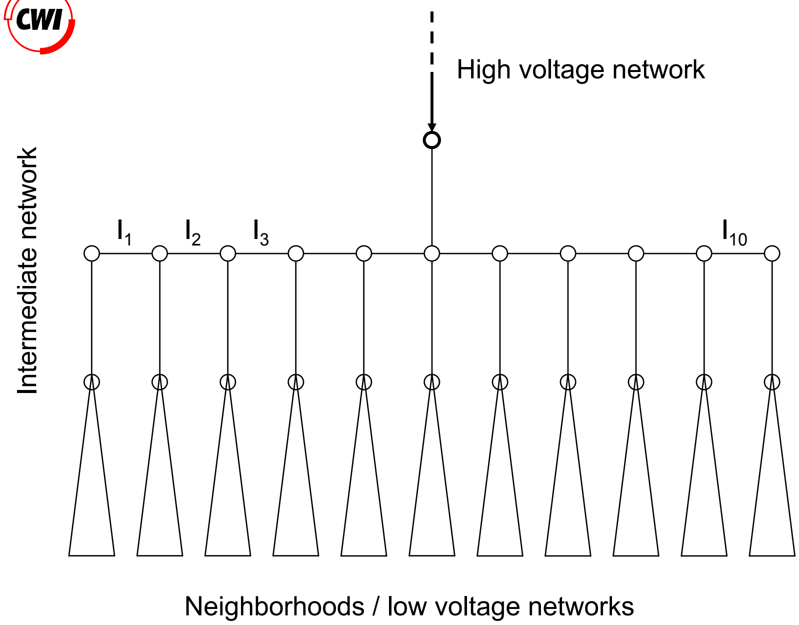
- Network simulation (not here; not CWI)
  - High voltage net
    - simulation TenneT supply (procurement)
    - basic scenarios modeled
      - stabilty, weak net, crashing net..
  - *Intermediate voltage net*
    - detailed physical simulation
    - various measure points
    - various aggregated performance measures possible
  - Low voltage net
    - simulation energy demand from intermediate net
- Scenarios
    - sun energy possibilities (clouds, wind, ..)

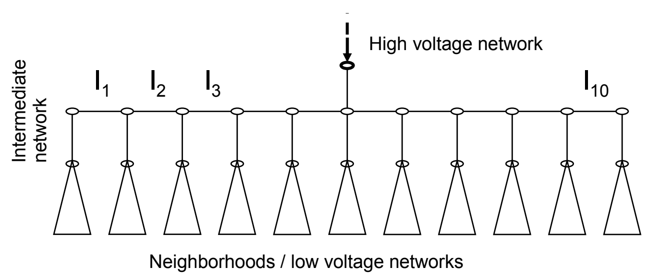


Intermediate Network

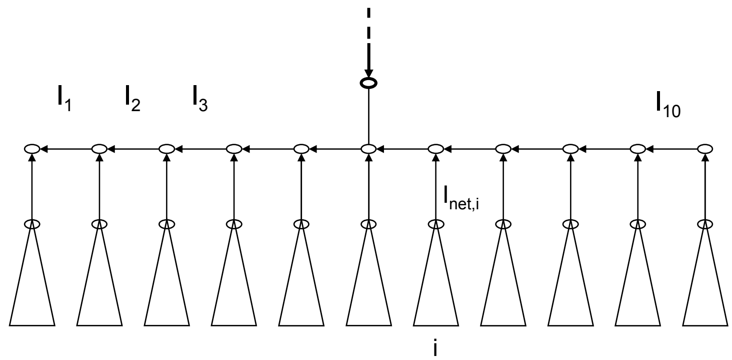
- Intermediate net
  - Physical/ empirical model that described energy supply through this net
    - 1 sec. resolution
  - Safety and health model of net
    - tripping, safety components, optimization interface
  - Reduce costs and aging
    - Avoid too high currents
    - Aging network (wear-out)
      - Extension of economical and physical lif
    - Replacement very expensive
  - Model/simulation for optimization



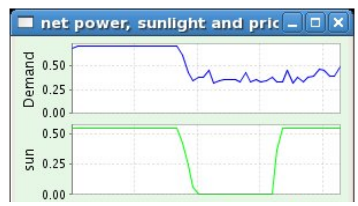




- Free current: per network piece (link)
- Costly current: $I' = I - \delta\ k$
  - k: piece number from nearest end (distance)
  - $0 \leq \delta \leq 1$
  - δ k: free current
  - Thick cable (pipe) in middle, thinner towards ends
- Costs: $\sum_k (I_k')^2$
  - Resistance / wearing out
- Simplified testing model
  - Classic/simplified electricity models
    - Water pipe like
  - Advanced electricity net simulator in development
  - Real-world usage next step



- Local demand per ngbh
- Local production
  - Sun energy
  - Weather aspects
- Net power supply (demand) per ngbh (as current):
  - $I_{net,i} = I_{prod,i} - I_{dem,i}$



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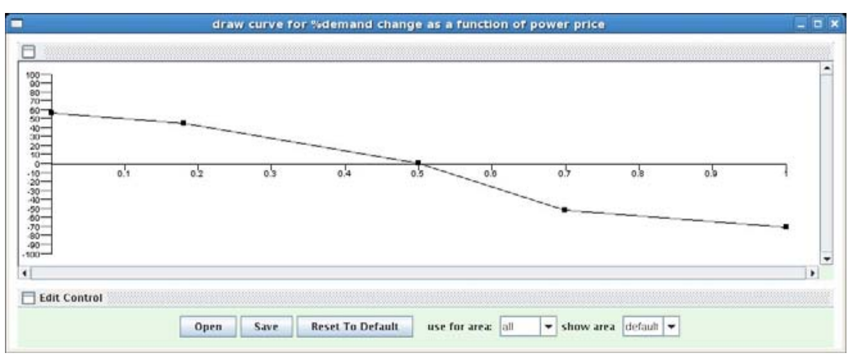
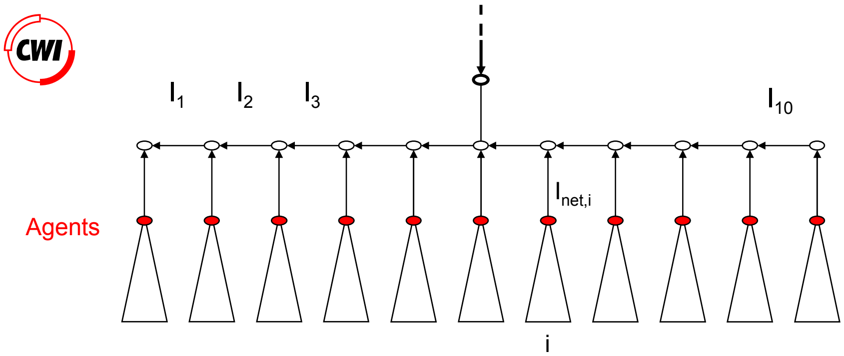
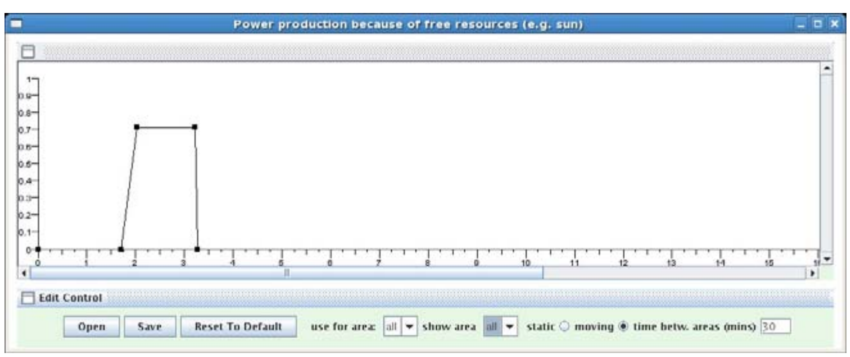


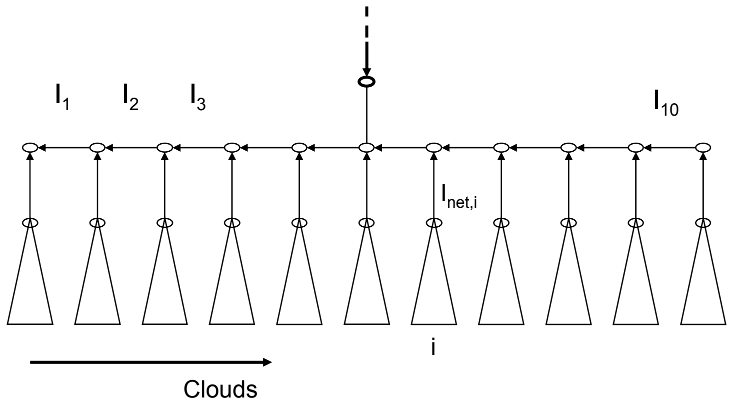
- Price / demand function
  - Percentage more or less than basic demand
  - $0 \leq$ local price ≤ 1
- Using local price to influence net supply
  - And gross demand



- Decentralized decision making
  - Per ngbh: pricing by agent
    - Or for e.g. different energy trader / brokers
  - Local information and decision
    - Possible
  - Local control and computation
    - Robust and stable
  - Distributed optimization



- Weather conditions
  - Moving clouds
  - Dip in sun energy production



- Changing weather conditions
  - Dynamic environment
  - Moving cloudiness
    - Moving cloud
    - Changing sun blockage

Local Decision Making

- Decision making per agent, idea:
  - Adaptive pricing based on given information
  - Basic, first implementation: derivative follower (DF)
    - Change price slightly (increase, decrease) (step), e.g. ± 0.01
    - Timed changes (seconds, minutes)
    - If cost improvement, then continue in same direction next time, otherwise reverse
  - Advanced versions of DF:
    - Adaptive step size (amplification and reduction)
    - Multi-dimensional (various parameters)
    - Using improvement information for step size
    - Using information about several nearby agents and costs
  - Here: basic DFs per agent
    - Some coordination between them

Local Decision Making

- Decision making per agent
  - Adaptive pricing based on given information
    - Local, aggregated, global
  - Several general design aspects:
    - Local models and information (per agents)
    - Local adaptive algorithms / heuristics / parameters (learning)
    - Coordination aspects
      - Between agents, as far as possible
  - Ongoing research
    - Further choices yet to make and investigate
  - Demo: first choices and implementation

Demo

- Demo….

Further Research

- Bidding strategies with
  - Bounded budget and resources
    - Previous research at CWI
  - Forecasting and learning
  - Improved models
  - Known long-term consumption/production (delay-able)
  - Short-term dynamic consumption/production
    - Usage models for consumers (ECN)
      - Freezer and boiler vs. television
      - Heat/power sources
    - Large producers and electricity suppliers and traders
      - Pricing policies and market mechanisms
      - Business models and constraints
- Realistic network simulators
- Real-world usage and deployment

Case: Conclusion

- Decentralized market mechanisms
  - Multiple parties
    - Large power generators
    - Energy traders, distributors, and brokers
    - Consumers / prosumers
      - Local demand and supply

- Important for optimization and distribution problems
- First phase research
  - First, simple modeling and demonstration results
  - Advanced modeling and solutions to be researched
- Trajectory like DEAL project in research

Conclusion

- Learning and economic optimization for energy-related problems
  - Decentralized decision making
  - Several substantial results available
  - Wide open field
    - Research
    - Applications
    - Many open problems
- Interest from science and society

Conclusion

- Co-authors of papers:

  Sander Bohte
  Han Noot
  Pieter Jan ‘t Hoen
  Valentin Robu

- Thank you!