From Miles to Millimeter: On-chip Communication Networks

Alessandro Pinto

U.C. Berkeley

apinto@eecs.berkeley.edu

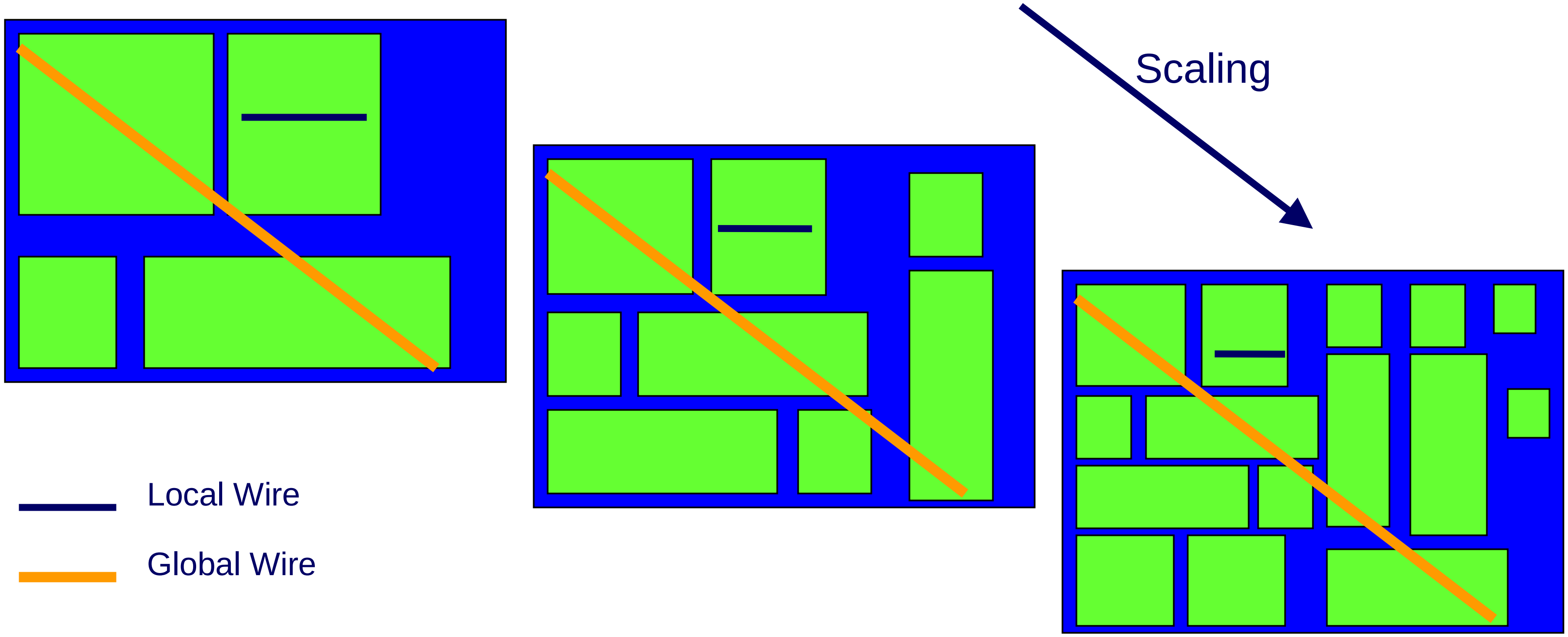
What

- Communication synthesis
  - What is the “best way” of transferring information between entities
- Problem Formulation
  - Who wants to communicate with whom
  - How he aspects the communication mechanism to behave
  - What is possible to built today
  - How to build a communication architecture that is cheap and satisfies the entities constraints while being feasible

Chips are small, why bother?

“As designs scale to newer technologies, they get smaller and their wires get shorter, and the relative change in the speed of wires to the speed of gates is modest.” M.A.Horowitz et.al “The future of wires”

“The real wire problem arises with increasing chip complexity and global communication costs.” M.A.Horowitz et.al “The future of wires”

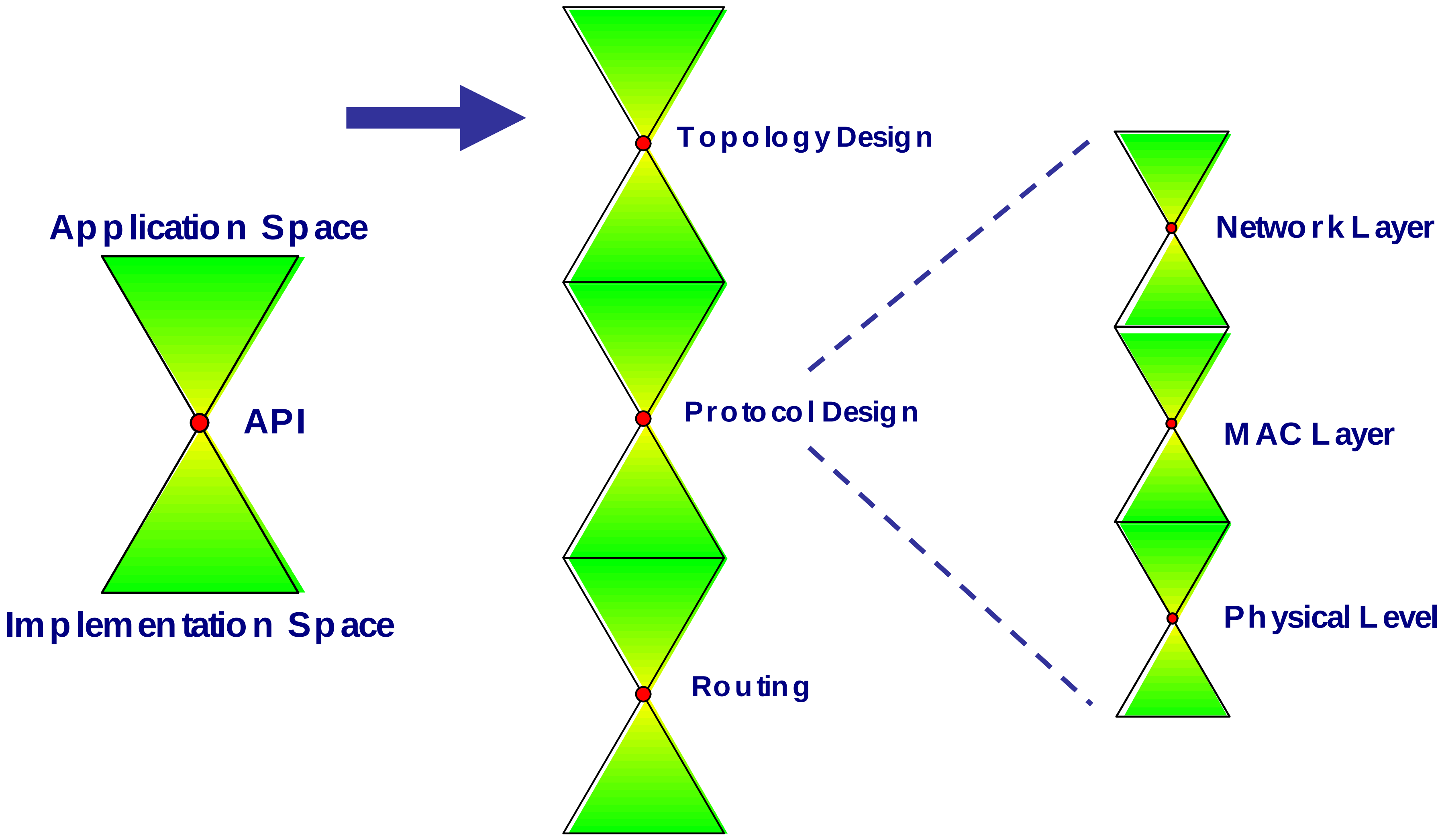


Networks vs. On-Chip Networks

- Internet major concern was to guarantee connectivity in case of attack
- Cost is mostly static
- Buffers memory is not a problem (512MB is still cheap)
- Number and complexity of protocol layer is important only for performance issues

- Full connectivity is not the major concern
- Now cost is mostly dynamic (power)
- Registers are expensive
- The protocol must be very light
- In the future error correction might become a reality

Communication Platform Stack



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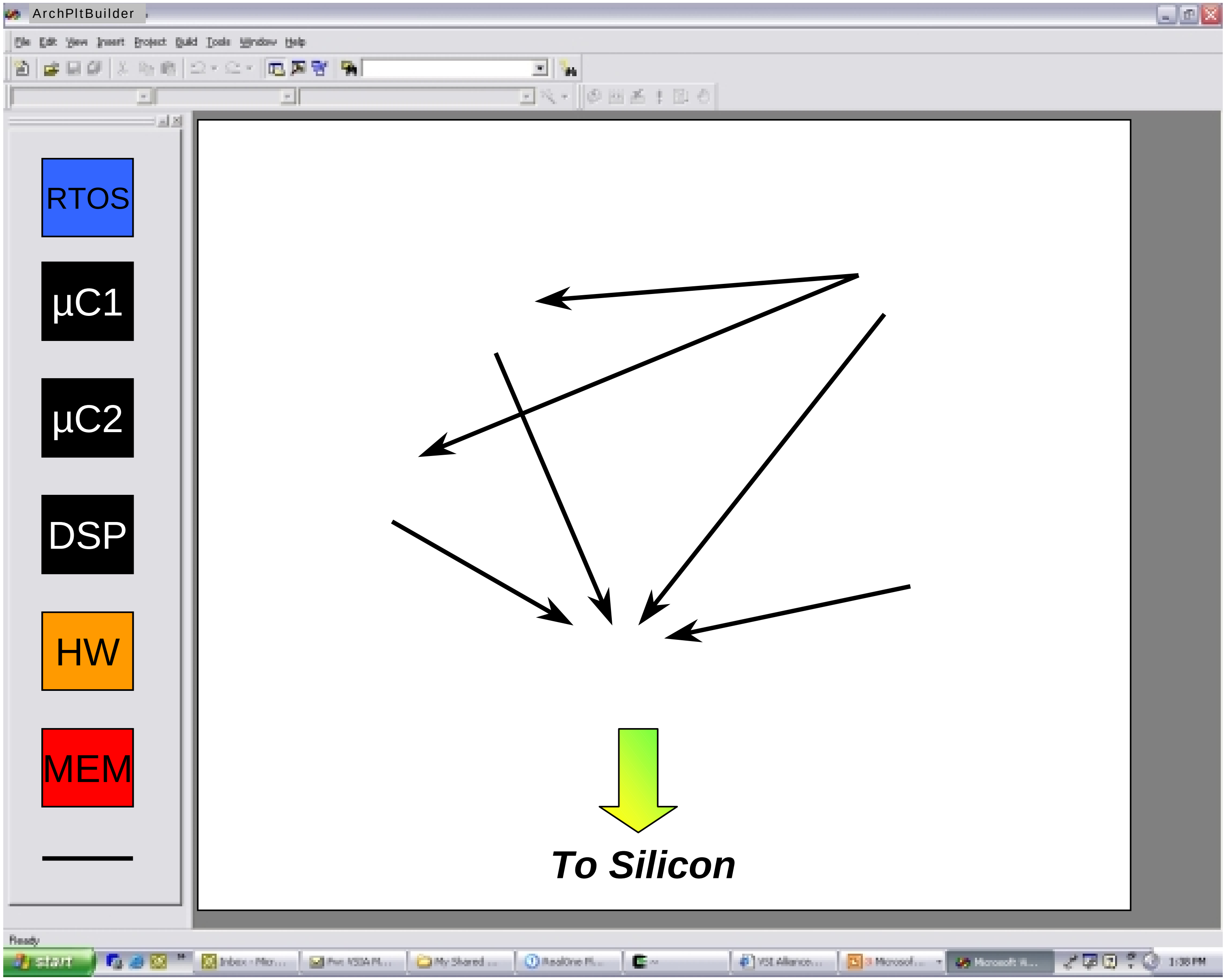
The Problem



Basic Definitions: Comm. Graph

- $G(V,E,P,\omega)$
  - $V = S \cup V' \cup D$
    - S,D not emtpy
  - $P = X_i\ pi$ is a performance domain
  - $\omega: E(G) \to P$
  - If the graph is placed
  - $\Pi: V(G) \to Pos$

- $C_e: E(G) \to Cost,\ C_v: V(G) \to Cost$
- $C_G = \sum_{e \in E(G)} C_e + \sum_{v \in V(G)} C_v$

A More General Defintion

- Two types of quantities
  - Series (e.g. position of nodes)
  - Parallel (e.g. bandwidth). **Must** sum up to 0 on a cut
- $P=P_S \times P_P$
- Communication Graph
  - $G(V,E,P,\omega,\Pi)$
  - $\omega: E(G) \rightarrow P_P$
  - $\Pi: V(G) \rightarrow P_S$

Flows

- Defined as usual in flow networks
- $f: V(G) \times V(G) \rightarrow P_P$
- Flow between two nodes:
  - $F(u,v) = \max (f(u,v))$

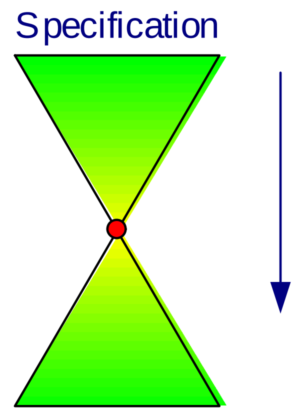
Graph Ordering

- $G_1 \subseteq G_2$
  - $S_1 = S_2$, $D_1 = D_2$, $\Pi_1|_{S1,D1} = \Pi_2|_{S2,D2}$
  - $|V'_1| \geq |V'_2|$
  - For all si,dj, $F_1(si,dj) \geq F_2(si,dj)$

- G1 *implements* G2

Communication Constraints Graph

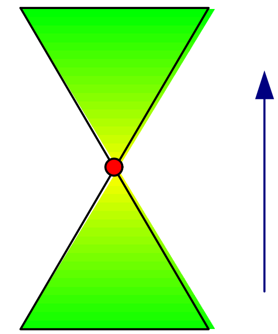
- Obs.: if $V'=\emptyset$ the $F(u,v) = \omega(e(u,v))$



Def.: A ***Communication Constraint Graph*** is a communication graph such that $V'=\emptyset$

Implementation Graph

- Given a communicaiton grpah G, define J(G) = {G' | G' $\subseteq$ G }



Implementation

Def.: The ***Implementation Graph*** of a communication graph G is the solution to the optimization problem

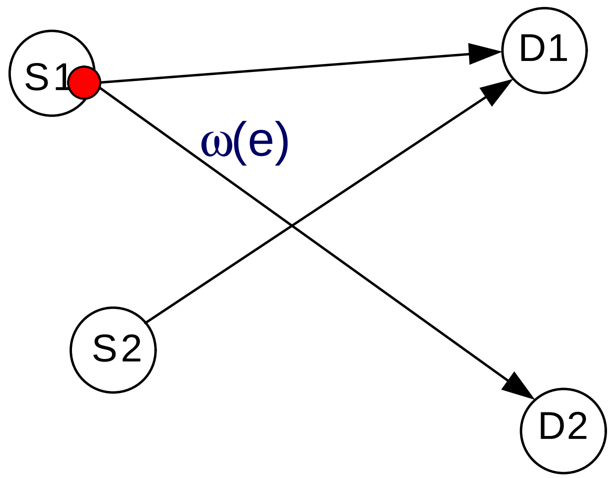
$$\min_{G' \in J(G)} C_{G'}$$

The Optimization Problem

- Given a Communication Constraint Graph G, find its Implementation Graph G'

- Obs.:
  - Two vertices s.t. $\Pi(n_1) = \Pi(n_2)$ can be considered to be the same vertex
  - An edge s.t. $\omega(e) = 0$ can be removed
  - E connected minimum tree with n leaves has at most n-2 non leaves vertices
  - A connected tree can be obtained by contraction or by removing edges

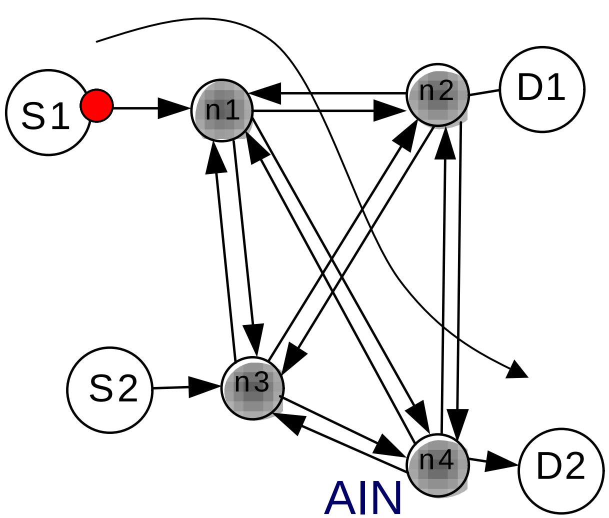
The Optimization Problem



$$\min_{\omega',\Pi'} C(G')$$

$$sbj\ to\ \ G$$

$$\downarrow$$



$$\min_{\omega',\Pi'} C(G')$$

$$sbj\ to\ \ \forall e(s_i, d_j) \in G,$$

$$A' f' \geq \omega(e) d$$

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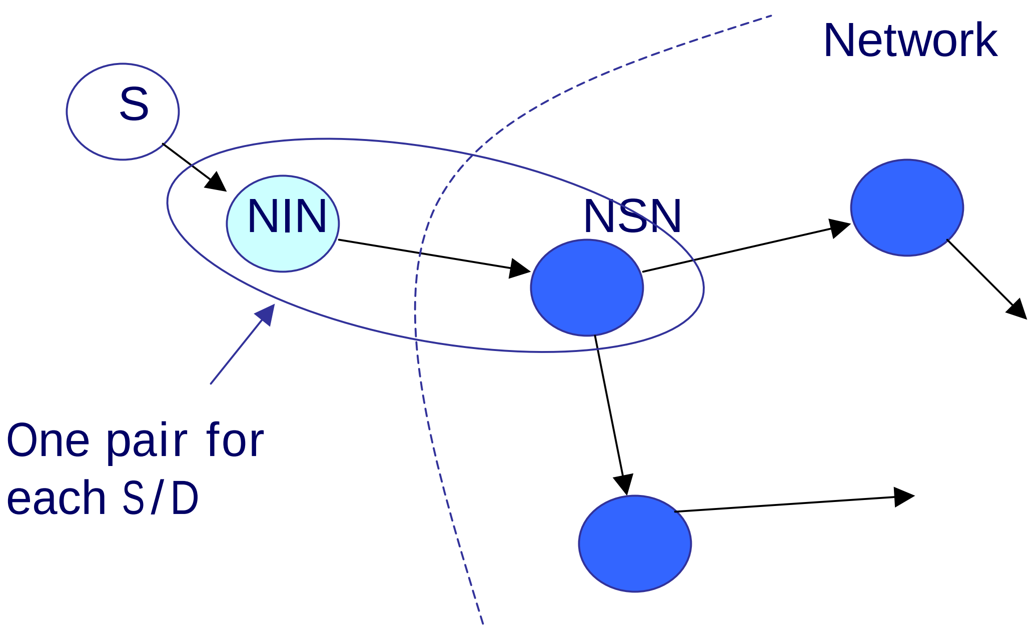
Put the protocol into the picture

- As you noticed I use ≥ for the flows
- Three possibilities:
  - The topology design relies on the protocol
    - The protocol performance/cost impact the topology
  - The protocol design relies on the topology
    - The topology performance/cost impact the protocol
  - A joint optimization is carried out (best result but very difficult)

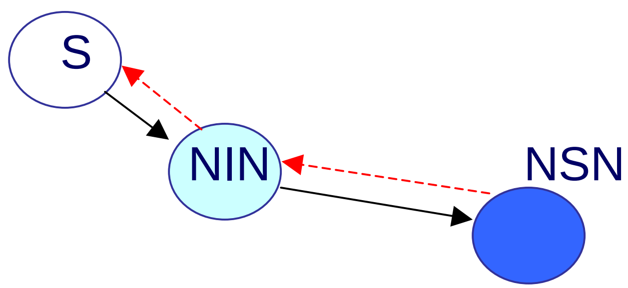
Splitting the nodes

- Each AIN is split into two nodes:
  - Network Switching Node (NSN)
  - Network Interface Node (NIN)



Trade Off Example

- Characterize each source with ba,bm,bl,br
  - Average b., maximum b., maximum burst length, maximum blocking rate
- Simple back-pressure mechanism: activate a signal to freeze the source (correspond to slowing down the source)



Trade Off Example: case 1

- Optimize the protocol considering
  - Queue length
  - Blocking time

$$\min_{br} \sum_{S} \left(k_S br_S + N_S(br) \right)$$

$$sbj.\ to\ \ \forall e(NIN_i, NSN_i),$$

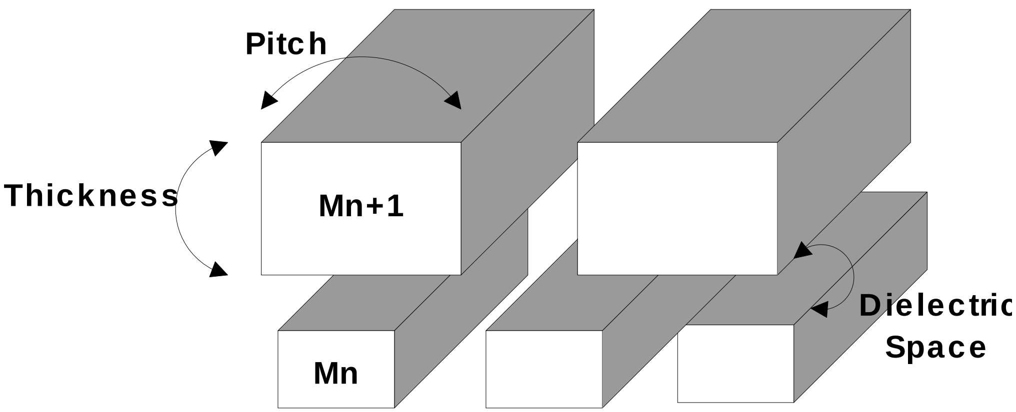
$$\omega(e) = ba_i$$

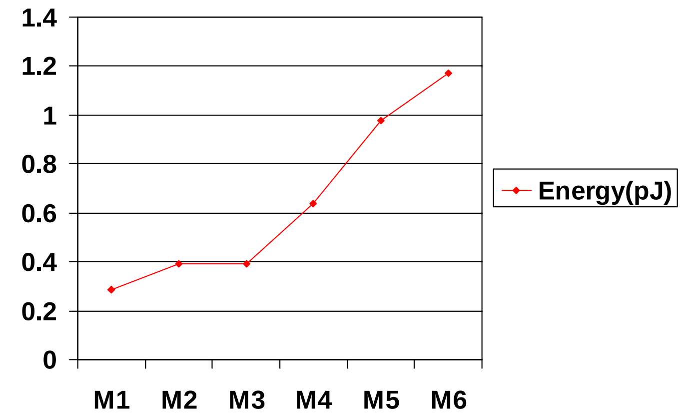
- Optimize the topology in the average case
  - This is an abstraction of the protocol performances

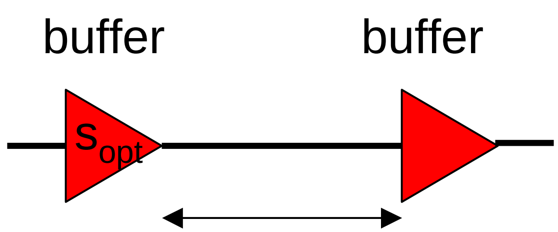
Trade Off Example: case 2

- G' is given (the topology is fixed)
  - For each (si,dj), F(si,dj) is known
- All the things we have seen in class
  - Find the routing algorithm
  - Find the flow control algorithm

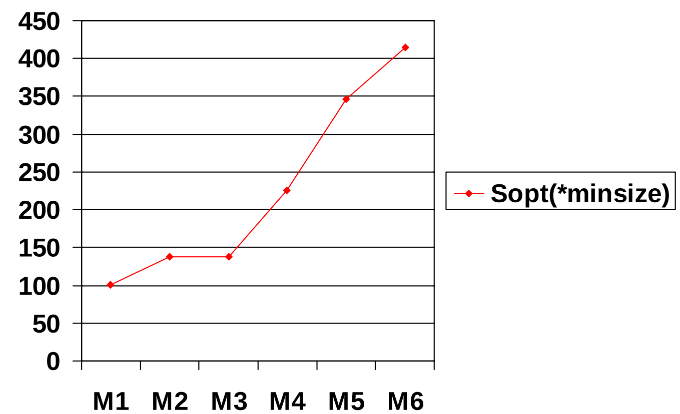
Just a Taste of the Library







l_{crit} $\tau_{crit} \approx 17\, ps$



$$P \propto E_s \; f \, \frac{l}{l_{crit}}$$

Conclusions

- The notion of communication graph has been introduced
- An optimization problem has been derived for the synthesis of networks
- The interaction between protocol and topology optimization has been analyzed

Future Work

- Get the software running
  - Find a good NLP package
- Solve other mixed integer programming problems
  - Path uniqueness
- Interface with other tools
  - Protocol synthesis
  - Edge covering
  - Interface Synthesis
- Use it