From Miles to Millimeter: On-chip Communication Networks

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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
“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.
The Problem
**Basic Definitions: Comm. Graph**

- \( G(V,E,P,\omega) \)
  - \( V = S \cup V' \cup D \)
    - \( S,D \) not empty
  - \( P = X_i \) is a performance domain
  - \( \omega: E(G) \rightarrow P \)
  - If the graph is placed
  - \( \Pi: V(G) \rightarrow \text{Pos} \)

- \( C_e: E(G) \rightarrow \text{Cost}, \ C_v: V(G) \rightarrow \text{Cost} \)

- \( C_G = \sum_{e \in E(G)} C_e + \sum_{v \in V(G)} C_v \)
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

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

- $G_1$ implements $G_2$
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 communication graph $G$, define $J(G) = \{G' \mid G' \subseteq G\}$

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

\[ \min_{\omega', \Pi'} C(G') \]
\[ \text{subj to } G \]
\[ \min_{\omega', \Pi'} C(G') \]
\[ \text{subj to } \forall (s_i, d_j) \in G, \quad A' f' \geq \omega(e) d \]
Put the protocol into the picture

- As you noticed I use $\geq$ 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)
Each AIN is split into two nodes:
- Network Switching Node (NSN)
- Network Interface Node (NIN)

One pair for each S/D
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

\[
\min \sum_{br} (k_s br_s + N_s (br))
\]

\[
sbj. to \ \forall e(NIN_i, NSN_i), \ \omega(e)=ba_i
\]

- 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

Pitch

Thickness

Dielectric Space

buffer

buffer

$S_{opt}$

$\tau_{crit} \approx 17 \text{ ps}$

$P \propto E_s \int \frac{l}{l_{crit}}$
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