Energy Tradeoff among Communication, Computation and Caching with QoI-Guarantee in Wireless Sensor Networks

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Motivation and Model

Energy is one fundamental limit of sensors. Communication, Computation and Caching consume energy: computation and caching both reduce communication costs:

- How much to compress the data?
- Where to cache the data?

A tree-structured Network:

- Leaf nodes generate data and sink node serves requests for these data
- Data transmitted along paths causes transmission, reception, computation and caching costs
- Decisions variables at each node for each data: compression ratio (real) and caching decisions (binary)
- Goal: minimize the total energy over the network subject to QoI and capacity constraints
- Non-convex Mixed Integer Nonlinear Programming (MINLP): NP-hard

$$\min_{\boldsymbol{\delta},\boldsymbol{b}} \quad E^{\text{total}}(\boldsymbol{\delta},\boldsymbol{b}) \triangleq \sum_{k\in\mathcal{K}} \left(E_k^{\text{C}} + E_k^{\text{R}}\right)$$

$$\text{s.t.} \quad \sum_{k\in\mathcal{K}} y_k \prod_{i=0}^{h(k)} \delta_{k,i} \geq \gamma,$$

$$b_{k,i} \in \{0,1\}, \forall k \in \mathcal{K}, i = 0, \cdots, h(k),$$

$$\sum_{k\in C_v} b_{k,h(v)} y_k \prod_{j=h(k)}^{h(v)} \delta_{k,j} \leq S_v, \forall\, v \in V,$$

$$\sum_{i=0}^{h(k)} b_{k,i} \leq 1, \forall k \in \mathcal{K},$$

Where

$$E_k^{\text{C}} = \sum_{i=0}^{h(k)} y_k f(\delta_{k,i}) \prod_{m=i+1}^{h(k)} \delta_{k,m},$$

$$E_k^{\text{R}} = \sum_{i=0}^{h(k)} y_k (R_k - 1) \left\{ f(\delta_{k,i}) \prod_{m=i+1}^{h(k)} \delta_{k,m} \left(1 - \sum_{j=0}^{i-1} b_{k,j}\right) + \left(\prod_{m=i}^{h(k)} \delta_{k,m}\right) b_{k,i} \left(\frac{w_{ca} T}{R_k - 1} + \varepsilon_{kT}\right) \right\}.$$

Algorithm: V-SBB

Symbolic Reformulation: Transform non-convex and non-linear terms into linear and convex terms.

Variant Spatial Branch and Bound: Eliminate bound-tightening steps in SBB, improving computational complexity and convergence.

Evaluation

We evaluate the performance of V-SBB and the energy efficiency of our formulation through tree structured networks:

- V-SBB, achieves ε-global optimal solution in reasonable time and is more robust to varying network parameters.
- V-SBB outperforms other solvers: NOMAD, GA and Bonmin.
- Our joint optimization framework over communication, computation and caching (C3) improves energy efficiency by as much as 88% compared to the optimization over communication and computation (C2), or communication and caching.

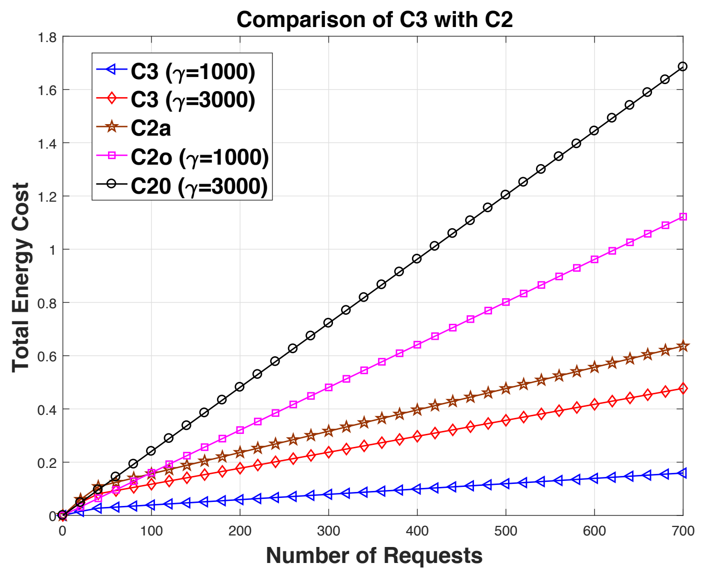

Figure 1: Comparison of C3 and C2 optimization for a seven-node binary tree network.

Solver	γ =1		γ =5		γ =50	
	Obj.	Time (s)	Obj.	Time	Obj.	Time
Bonmin	0.0002	0.214	0.0003	0.224	0.0021	0.364
V-SBB	0.00011	1871	0.00019	1243	0.0020	3325
Imp. (%)	52.45		50.30		4.62	

Table 1: Comparison between V-SBB and Bonmin for a seven-node binary tree network.

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