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Segmentation and Predictive Scheduling Policy under Multiple Sources

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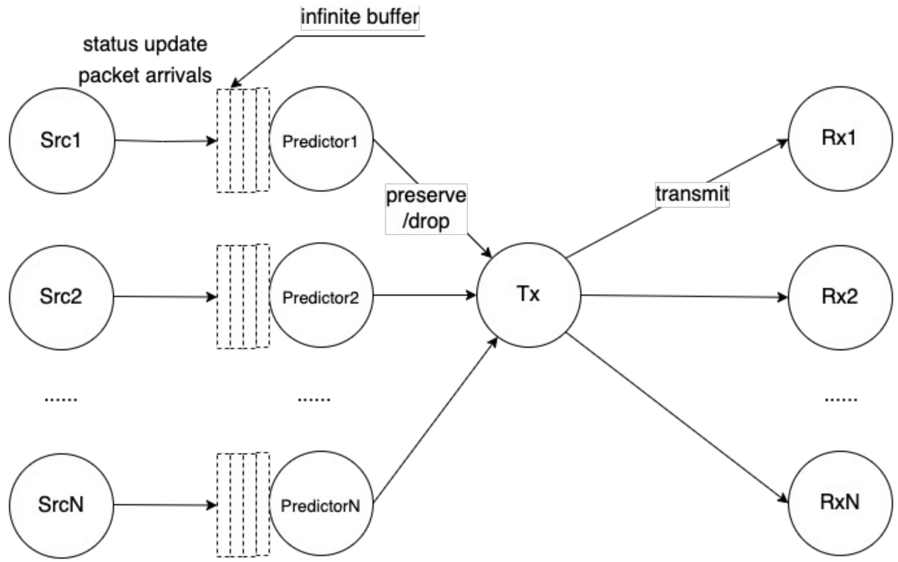
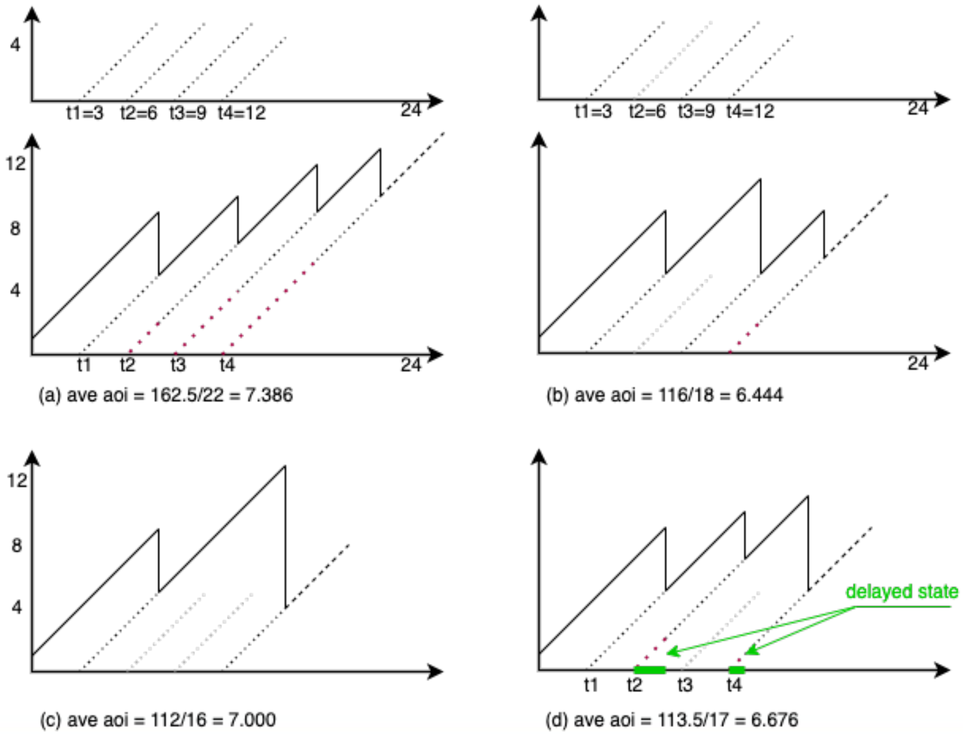
System Model



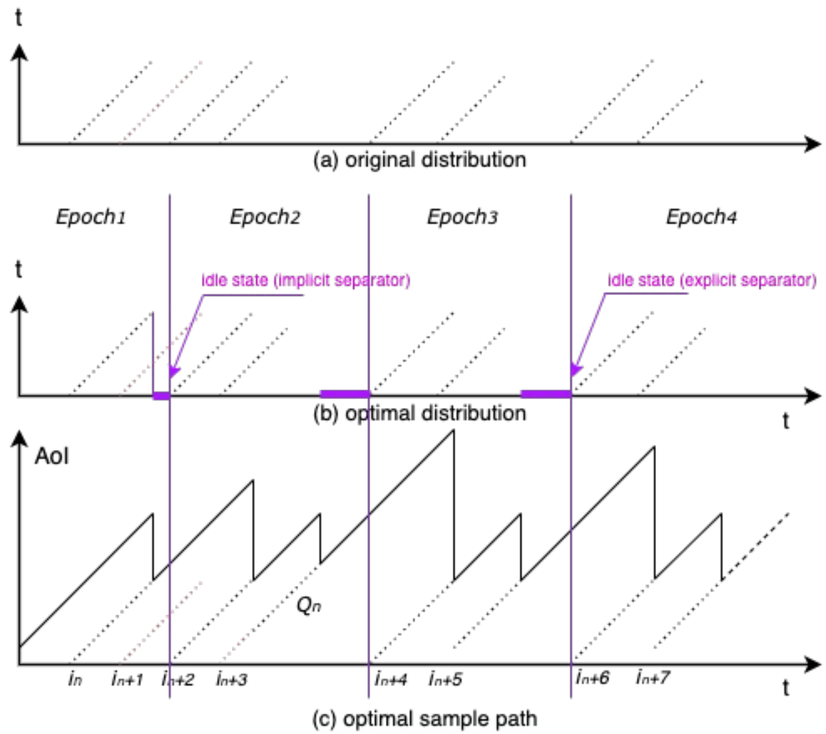
- predictor estimates inter-arrival time
- determine preserving or dropping
- known each inter-arrival and service time
- infinite buffer assumption
- multiple source-destination pairs
- packets arriving independent from others
- one channel shared by multiple sources

Problem Definition



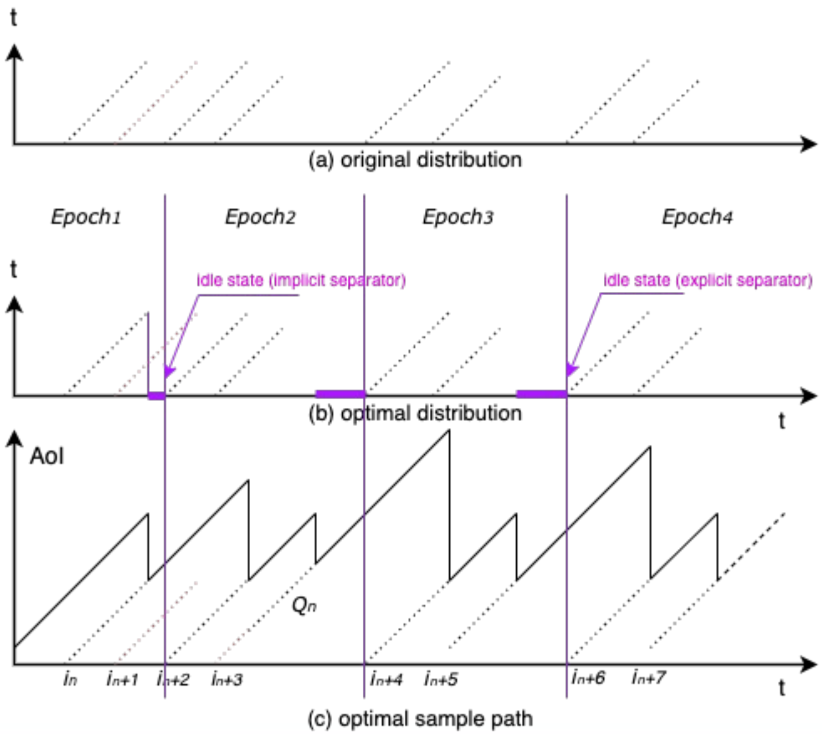
- large possible combinations of 2^k
- significant length of sequence k
- unaffordable time, energy and computing power

Prediction and Segmentation



- minimum AoI in an epoch n
- synchronized initial age and final age
- separator under multiple sources
  - (idle waiting time, synchronization)

Comparison between Transition Zones



- compare between possible policies
- minimum epoch-AoI but different final ages
- an arbitrary AoI of n^{th} attempt epoch under any major scheduling policy π^M and any minor scheduling policy π^T:
  - $\phi_n(\pi^M, \pi^T) = \min_{\pi^M}\left[\sum_{i=1}^{k}\left(\varphi_i^{\pi^M}\right)\right] + \min_{\pi^T}\left[\sum_{j=1}^{k}\left(\varphi_j^{\pi^T}\right)\right]$
  - $\phi_n^*(\pi^{M*}, \pi^{T*}) \le \phi_n(\pi_u^M, \pi_u^T), u \in \{1 \quad 2 \quad \cdots \quad 2^{k_n}\}$
- sample path synchronization under any two initial ages $A_0^{(1)}$ and $A_0^{(2)}$

Asymptotic Synchronization

- any scheduling policies $\{\pi_i\}$ for a given attempt epoch n
  - $\forall i \in [1 \quad 2 \quad \cdots \quad 2^{l_n}]$, $l_n = k_{n+1} - k_n$
- rearrange according to their corresponding $cAoI$ value

Sync Proof (1) – scheduling policy set

- any scheduling policies $\{\pi_i\}$ for a given attempt epoch n
  - $\forall\, i \in [1 \quad 2 \quad \cdots \quad 2^{l_n}],\, l_n = k_{n+1} - k_n$
- rearrange according to their corresponding $cAoI$ value
  - $\pi_i \in \{\pi_0^* \quad \pi_1 \quad \pi_2 \quad \cdots \quad \pi_{2^{l_n}}\}, i \in N$
  - $i \in \{0 \quad 1 \quad 2 \quad \cdots \quad i \quad i+1 \quad i+2 \quad \cdots \quad 2^{l_n}\}$
- sort scheduling policies in descending order of $cAoI$ value
  - $\{\phi(n)_0^* \quad \phi(n)_1 \quad \phi(n)_2 \quad \cdots \quad \phi(n)_i \quad \phi(n)_{i+1} \quad \phi(n)_{i+2} \quad \cdots \quad \phi(n)_{2^{l_n}}\}$
  - $\phi(n)_0^* \leq \phi(n)_1 \leq \phi(n)_2 \leq \cdots \leq \phi(n)_k \leq \phi(n)_{k+1} \leq \phi(n)_{k+2} \leq \cdots \leq \phi(n)_{2^n}$
- assume that the difference between any two adjacent AoI (steps) $\phi(n)_{\mathrm{i}}$ and $\phi(n)_{\mathrm{i+1}}$
  - $\Delta\phi(n)_{\mathrm{i}} = |\phi(n)_{\mathrm{i}} - \phi(n)_{\mathrm{i+1}}| \gg \varepsilon > 0$

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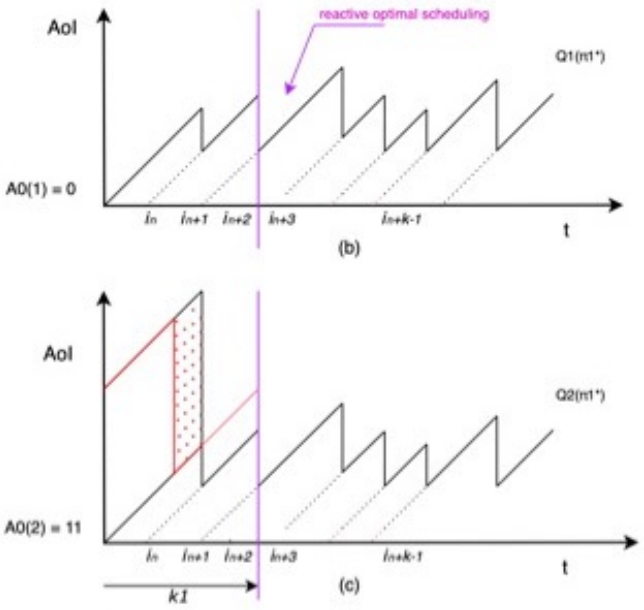
Sync Proof (2) – one near-optimal case



- optimal scheduling policy π^* and optimal sample path $\mathcal{P}^* = s(\pi^*, 0)$ for a given sequence with the initial age 0.
- optimal scheduling policies $\pi^*_{A_0}$ and optimal sample path $\mathcal{P}^*_{A_0} = s\left(\pi^*_{A_0}, A_0\right)$for a given sequence with the initial age A_0.
- obtain intermediate sample path $\mathcal{P}^*_{I-A_0} = s(\pi^*, A_0)$, by substituting optimal scheduling zero-policy π^* into the optimization with initial age A_0.
- distance between near-optimal $\phi(n)^*$ and $\phi(n)_{\mathrm{i}}$, equivalent to difference between $\mathcal{P}^*_{I-A_0}$ and $\mathcal{P}^*$.

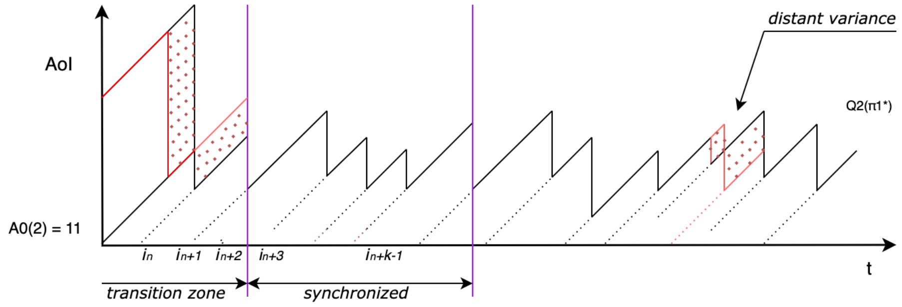
Proof (3) – limited number of basic blocks

- any $\phi(n)$ constructed by a sample path $\mathcal{P}$ under any scheduling policy π
- possible combination of selections from the same set of basic blocks, except for the only initial basic block
- limited number of common basic blocks for constructing any sample path $\mathcal{P}$
- difference $\Delta\phi(n)'_u$ between k-step optimizing sample path $\mathcal{P}^*_{I-A_0}$ with $\phi(n)^*$ and optimal sample path $\mathcal{P}^*$ with $\phi(n)_k$
  - $\Delta\phi'_u = \phi'_u - (\phi')^* = s(A'_0, \quad \pi'_u) - s(A'_0, \quad (\pi')^*)$
- -

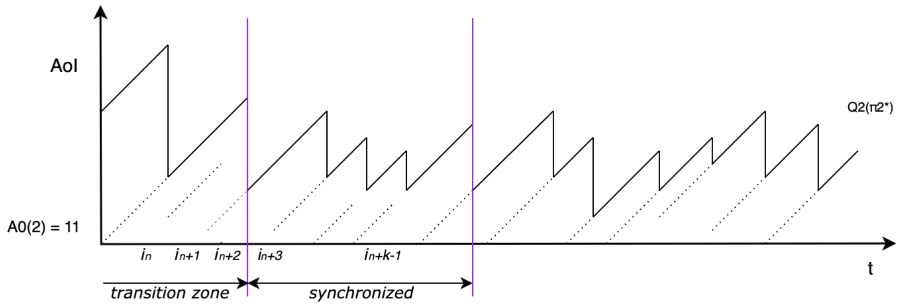
Proof (4) – different scope with limitation

- difference $\Delta\phi(n)'_u$ between k-step optimizing sample path $\mathcal{P}^*_{I-A_0}$ with $\phi(n)^*$ and optimal sample path $\mathcal{P}^*$ with $\phi(n)_k$
  - $\Delta\phi'_u = \phi'_u - (\phi')^* = s(A'_0, \quad \pi'_u) - s(A'_0, \quad (\pi')^*)$
  - $\phi^* = s(0, \quad \pi^*) \leq (\phi')^*$
  - $\Delta\phi'_u = \phi'_u - (\phi')^* \leq \phi'_u - \phi^* = s(A'_0, \quad \pi'_u) - s(0, \quad \pi^*)$
  - $\Delta\phi'_u \leq s(A'_0, \quad \pi'_u) - s(0, \quad \pi^*) = A'_0 \times (I_{l1} + X_{l1})$
  - $\Delta\phi'_u = \phi'_u - (\phi')^* \leq A'_0 \times (I_{l1} + X_{l1})$
  - $0 \leq \Delta\phi'_u \leq A'_0 \times (I_{l1} + X_{l1})$
- limited number of basic blocks between near-optimal and optimal
  - $k = \Delta\phi'_u / \phi_b$
  - $0 \leq k \leq [A'_0 \times (I_{l1} + X_{l1})] / \phi_b \ll \infty$

Proof (5) – vicinity mutation



(a)



(b)

- **Lemma 5 – vicinity mutation but distantness invariant:** For two packet sequences with distinct initial ages but identical inter-arrival times and service times, in terms of the two corresponding two optimal AoIs, the difference in process between the two should only occur during the period from initiation up to, but not including, complete synchronization, and should not be present after synchronization is achieved.

Proof (6) – synchronization occurrence

- **Lemma 5 –**
- limited

Proof (6) – syn with muti-sources