Proactive-Caching based Information Centric Networking Architecture for Reliable Green Communication in ITS

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Introduction

• **Problem statement and research motivation**
  In this research, the train system is stated for the case of ITS.
  – Nowadays, train is a popular public transportation vehicle.
  – The train's commuters also have high tendency to use their mobile devices for getting their interested information from Internet during the time they spend on train.
  – Motion of a commuter can be predicted from path of a train line and the moving direction, stopping time along with the moving time between two stations can be pre-determined.

• **Proposal goal**
  Construct a concrete model as a prototype of energy-efficient and reliable DAN (Data Aware Networking) based wireless communication technology within the context of ITS.

NOTE: In ITU (standardization) documentations, ICN (Information Centric Networking) concept is reflected as DAN (e.g. ITU-T, "Recommendation ITU-T Y.3033: Framework of data aware networking for future networks," 2014).
Proposed DAN Network Topology for ITS

- **5-level tree based topology** with server as root node
Proactive-caching scheme and smart scheduler

- **Proactive-caching based scheme**
  - **Choose aggregation points (Station CRs at level 2) as the location of proactive caching** for enhancing the scope of sharing of the content.
  - **Mechanism:** When the CP receives an interest asked for a content, that content data is divided into several segments then is pre-cached to N Aggregation nodes (expected number of stations that one commuter stays on the train).

- **Smart scheduler**
  - **decides** the **appropriate location** (station) for pre-caching and **calculate** amount of content segment should be cached.
  - the system **generates fake interest** (for same content) from the neighbor Aggregation node. **Moreover**, the pre-caching process for a suitable segment of content c to station N's CR **only happens in case** station (N-1) still get the interest for content c at that time → **prevent redundant content traffic**.
Green ICN Architecture for ITS

- $p_k$ is the probability that one content user can find a specific content $c$ at a CN (Content Node) level $k$
- $Q_k$ is the probability for a user traversing $k$ levels of the tree to find an interested content $c \in C$, $(K \geq 1)$

$$Q_k = p_{k+1} \times \prod_{l=1}^{k} (1 - p_l)$$
Content Node Rate Adaptive Scheme for Green Networking in DAN

**CN Rate Adaptive scheme**

- Let $R_k$ be the link rate enter on level $k$ CR for a content $c \in C$ and $R_{ICN}$ is the link rate with caching in the conventional ICN network, then maximum load in first level
  \[ R_1 = R_{ICN} \text{ and } R_1 > R_k (\forall k > 1) \]

- Let $S_k$ be the set of content come to a level $k$ router and $S$ is maximum number of contents that each ICN routers can cache

  \[ \rightarrow \text{Enhanced } R_k (1 < k \leq 4) \]

  - In case there is at least one popular content is asked
    \[ \text{Optimized } R_{k,ICN} = \alpha \{ R_{ICN} \left[ 1 - \min (P_{1c} + \sum_{i=1}^{k-2} Q_{lc}) \right] \}
    \forall \text{Content } c \in S_k \text{ and } |S_k| \leq S \]

  - In case only unpopular content(s) are asked
    \[ \text{Optimized } R_{k,ICN} = \alpha \{ R_{ICN} \frac{\max P_{1c}}{T_P} \left[ 1 - \min (P_{1c} + \sum_{i=1}^{k-2} Q_{lc}) \right] \}
    \forall \text{Content } c \in S_k \text{ and } |S_k| \leq S \]

  where $\alpha$ is the proportional coefficient of link rate and power consumption of Content Nodes (APs and CRs) and $\alpha \geq 1$.

  \[ \rightarrow \text{the Enhanced Link Adjusting Factor } E_A \text{ is defined as} \]

  \[ E_A = \frac{\text{Enhanced } R_{k,ICN}}{R_{ICN}} \quad (0 < E_A \leq 1) \]
Mathematical model for energy consumption evaluation

\[
E_{IP} = N \cdot E_{R-IP} + E_s \\
= N \cdot P_{R1-IP} \cdot T_w + N_1 \cdot P_{R2-IP} \cdot T_w + N_2 \cdot P_{R2,AP-IP} \cdot T_w + (P_{S1} \cdot T_w + P_{S2} \cdot T_w + P_{S3} \cdot T_w)
\]

where \(E_{R-IP}\), \(E_s\) are the energy consumed by a IP router and energy consumed by the server; \(P_{R1-IP}, P_{R2-IP}, P_{R2,AP-IP}\) are the embodied power of a network node (router/AP), working power of a IP router, and working power of an AP, respectively; \(N_1, N_2\) and \(N\) are the number of routers, number of APs, and number of CNs respectively \((N_1 + N_2 = N)\) and \(P_{S1}, P_{S2}, P_{S3}\) are the embodied power, power for server storage and operating power of a server (same value for both ICN and IP based network system), respectively. Besides, \(T_w\) is the working time of the whole network system.

\[
E_{ICN} = N \cdot E_{R-ICN} + E_s = N \left( P_{R1-ICN} \cdot T_w + P_{R3-ICN} \cdot T_w \right) + N_1 \cdot P_{R2-ICN} \cdot T_w + N_2 \cdot P_{R2,ICN,AP} \cdot T_w + (P_{S1} \cdot T_w + P_{S2} \cdot T_w + P_{S3} \cdot T_w)
\]

where \(P_{R1-ICN}, P_{R2-ICN}, P_{R3-ICN}\) are the embodied power, working power and power to cache memory of a ICN CN (CR/AP), respectively. For the purpose of power consumption evaluation, both the current IP-based network system and conventional ICN system share the same power consumption for servers, whereas a ICN node consumes slightly higher power compared to a normal IP node because of the CN’s caching function.

\[
Proposal E_{ICN} = \sum_{k=1}^{N} Enhanced \ E_{R-ICN,r_k} + Enhanced \ E_{S-ICN}
\]

\[
\sum_{k=1}^{N} Enhanced \ E_{R-ICN,r_k} = N \left( P_{R1-ICN} \cdot T_w + P_{R3-ICN} \cdot T_w \right) + \sum_{k=1}^{N} Enhanced \left[ P_{R2-ICN,r_k} \cdot T_{Ork} \right]
\]

\[
Enhanced \ E_{S-ICN} = (P_{S1} \cdot T_w + P_{S2} \cdot T_w) + \left[ P_F \cdot T_{Os} + P_I \left( T_w - T_{Os} \right) \right]
\]

where \(T_{Ork}\) is the operating time of CN \(r_k\) with proposed ALR design, and \(T_{Os}\) is the operating time of server S. Besides, assume that systems user server (CP) with 2 specific state: Idle mode when no content interest send to server and Full mode otherwise (there is at least one interest come to CP). Then let \(P_F\) and \(P_I\) are working power of Full mode and Idle mode, respectively.
### Simulation Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Connection bandwidth</td>
<td>1Gbps</td>
</tr>
<tr>
<td>Content size</td>
<td>1000MB</td>
</tr>
<tr>
<td>Payload size (Content Chunk size)</td>
<td>1024 bytes</td>
</tr>
<tr>
<td>Content Store Size</td>
<td>20,000 objects</td>
</tr>
<tr>
<td>Number of Station CRS (Aggregation Node)</td>
<td>4</td>
</tr>
<tr>
<td>Numbers of child nodes which each &quot;parent&quot; has</td>
<td>2</td>
</tr>
<tr>
<td>Content request rate</td>
<td>25% of network utilization</td>
</tr>
<tr>
<td>Content Popularity distribution</td>
<td>Zipf Distribution (similar to Zipf-like distribution)</td>
</tr>
<tr>
<td>Time stay at each Station &amp; Time move between 2 stations</td>
<td>18s &amp; 90s</td>
</tr>
</tbody>
</table>

Proposal results and discussion

- Power consumption comparison in case of different cache size (GB)

Though the conventional ICN (DAN) system consumes slightly more power than the current IP-based system, simulation with tree topology proves the efficiency proposed Green ICN system compared to the IP-based system (about 20% power saving with suitable hardware support).
Proposal results and discussion

- Performance evaluation for Average Hop Count of ITS

- The Average Packet Hop count is kept stable at value of 2 with the simulation time as shown, except the cases that the Mobile Node (MN) is involved in the Hand-offs period when it move to change the Point of Attachment (PoA). This is the result of proposed proactive caching strategy.
Conclusion and Future work

• In this paper, we propose and evaluate a cross-layer wireless content access model in ICN (DAN) for ITS (train/railway system)
  – Integrate both green networking and innovated proactive-caching based scheme in ICN mobility together to raise energy efficiency and effectiveness for the goal of green mobility in ICN.
  – The simulation results corroborate theoretical idea and prove the efficiency of proposed scheme, compared to both current IP-based network and conventional ICN design.
  \(\rightarrow\) propose our work for DAN standardization process of ITU for a reliable and safe human-centric system toward an ubiquitous intelligent and trusted society.

• Future work
  – Extend our proactive caching scheme in ICN with various practical use-cases with different kinds of content services, such as: VoIP, Multimedia Services, etc in larger scalability for Future Mobile Communication.
  – Conduct the scheme under field experiment to further evaluate proposal's efficiency.
Thank you very much for your kind attention!

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