Successive Interference Cancellation: A Back of the Envelope Perspective

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Simple Case of Wireless Transmission

Decoding successful if:

$$\text{SNR} = \frac{\text{Signal}}{\text{Noise}} = \frac{\mathcal{N}}{\sim} > \text{Threshold}$$
What if parallel transmissions?

Decoding successful only if:

\[
\text{SINR} = \frac{\text{Signal}}{\text{Interference} + \text{Noise}} = \frac{\sim + \sim}{\sim} > \text{Threshold}
\]
Collision

Decoding fails because:

\[
\text{SINR} = \frac{\text{Signal}}{\text{Interference} + \text{Noise}} = \frac{\sim}{\mathcal{N} + \sim} < \text{Threshold}
\]
Successive Interference Cancellation

Thus, it is as if SIC can “uncollide” signals, resulting in two successful transmissions.
Capacity with SIC

\[ \text{SNR} = R_{\text{blue}} = \log \left( 1 + \frac{S_{\text{blue}}}{\text{noise}} \right) + \text{SINR} = R_{\text{green}} = \log \left( 1 + \frac{S_{\text{green}}}{S_{\text{blue}} + \text{noise}} \right) \]

- Rate of blue signal remains same
- Rate of green signal far less
- Strong signal penalized, weak signal gets all the benefits
Channel Capacity w/o SIC

\[
\text{SNR} = \frac{R_{\text{blue}}}{\text{noise}} = \log \left( \frac{|S_{\text{blue}}| + \frac{S_{\text{green}}}{\text{noise}}}{\text{noise}} \right)
\]

\[
R_{\text{sic}} = \log \left( 1 + \frac{S_{\text{blue}} + S_{\text{green}}}{\text{noise}} \right)
\]

\[
\text{SNR} = \frac{R_{\text{green}}}{\text{noise}} = \log \left( \frac{|S_{\text{green}}| + \frac{S_{\text{green}}}{\text{noise}}}{\text{noise}} \right)
\]

\[
R_{\text{woSIC}} = \max( R_{\text{blue}}, R_{\text{green}} )
\]

Gain_{sic} =
SIC PHY Capacity Gain

![Graph showing the relationship between SNR for transmitter 1 in dB and SNR for transmitter 2 in dB, with SIC gain on the y-axis. The graph displays a gradient from black to yellow, indicating different SIC gains. The x-axis is labeled 'SNR for transmitter 1 in dB', and the y-axis is labeled 'SNR for transmitter 2 in dB'. The SIC gain is indicated on the right side of the graph, ranging from 1 to 1.6.]
SIC PHY Capacity Gain

Max SIC gain when equal signal strengths
As protocol designers ...

**We were tempted to schedule packet transmissions of similar signal strengths ...**

Our interpretation was that ...

**maximizing SIC capacity will maximize throughput**

But let’s verify that ...
SIC: A Packet Perspective

- Stronger green packet has to be at low rate
- Weaker blue packet can be at a high rate

MAC Layer throughput can actually suffer
Mathematically ...

\[ \text{Time}_{\text{SIC}} = \max \left( \frac{L}{R_{\text{blue}}} , \frac{L}{R^*_{\text{green}}} \right) \]

\[ \text{Time}_{\text{woSIC}} = \frac{L}{R_{\text{blue}}} + \frac{L}{R_{\text{green}}} \]
SIC Throughput Gain

The diagram illustrates the SIC gain as a function of SNR for Client 1 and SNR for Client 2. The color scale represents the SIC gain, with higher values indicating greater gain.
SIC Throughput Gain

Max throughput gain when signal strengths are 2:1
Why is This Happening?

\[ \text{T1} \rightarrow \text{AP} \rightarrow \text{T2} \text{ Interferer} \]

\[ \sim + \sim = \sim \]

\[ R_{\text{green}} \rightarrow \]

\[ R_{\text{blue}} \rightarrow \]
Capacity Vs. Throughput

We expected:
- Maximizing SIC capacity will maximize throughput

Reality:
- Equal signal strengths maximize capacity but not throughput
Can’t we improve MAC layer throughput with SIC

by reducing size of the hole ...
We study SIC enabled throughput in two scenarios

1. Two transmitters transmitting to a common receiver

2. Two transmitters transmitting to distinct receivers
We begin with

1. Common receiver

We consider:

1. Power control
2. Scheduling
3. Multirate packetization
4. Packet packing
(1) Power Control

- Reduce power of blue Tx such that

\[
\text{SINR}^*_\text{green} = \frac{N}{\tilde{N}} = \frac{R_{\text{green}}}{R_{\text{blue}}} = 2^* \sim
\]

Reduce
(2) Client Pairing
(2) Client Pairing

T1, T3

T2, T4
Multirate Packetization

- Send the strong packet at high rate after weak packet has finished

\[ R^*_{\text{green}} \quad \rightarrow \quad R_{\text{green}} \]
\[ R_{\text{blue}} \]
Packet Packing

- Send multiple packets to fill up the hole
- Hard because stronger signal modeling becomes difficult

\[ R^*_{\text{green}} \]

\[ R_{\text{blue}} \]
How Does Adaptation Help?

- Perform Monte Carlo Simulations
Upload Performance with MAC Modifications

Considerable Improvement with Adaptation
2. Distinct Receivers

Situations much less favorable to SIC
2. Distinct Receivers

Main Concern:

• T1 will transmit at best possible bit-rate to R1

• R2 has to decode T1’s signal at this bit rate...
  - Despite the presence of T2’s signal
2. Distinct Receivers

Thus, necessary (but not sufficient) condition:

• R2’s interferer(T1) must be closer than its own transmitter(T2)

• T1’s own receiver(R1) must be further than interfered receiver(R2)
Gains available when all conditions hold
Gains available when all conditions hold

How often do these SIC permissible topologies occur?
Monte Carlo Simulation

Gain with SIC in less than 10% of the cases
Can protocol adaptation help?

1. Power control
2. Scheduling
3. Multirate packetization
4. Packet packing
Not many topologies support SIC … thus limited scope for protocols
Implication on Network Architecture?
Residential WLANs:
• Neighbors AP may be stronger
• Some SIC scenarios possible

Enterprise WLANs:
• Clients likely to associate with stronger AP
• Such scenarios unlikely

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Of course:

SIC throughput gains will increase if bit rate T1->R1 is sub optimal

However, rate adaptation schemes such as SoftRate and AccuRate approaching optimality ... little room for SIC
Mismatch with Literature?

Interference cancellation has been shown to be beneficial ...
Our observations are not in conflict

In existing schemes, interfering bits are known
ZigZag, ANC, CSMA/CN, Full Duplex ...

This paper investigates the case of
\textbf{Unknown Interference Cancellation}
Conclusion

- Successive Interference Cancellation
  - A PHY layer capability to “uncollide” transmissions

- Throughput gain is not immediate from SIC
  - Permissible bit rates impact the length of packet transmission times
  - Creates under-utilization of the channel

- Protocol adaptations possible to cope with problem
  - Some gains available for common receiver scenario
  - However, limited gains for networks with distinct receivers
SIC aware protocol design fraught with pitfalls …

Consider doing a back-of-the-envelope calculation before plunging into system design
Questions, comments?

Thank you

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