Earlier works utilize a gate mechanism for each agent to decide whether to communicate their messages.

* ATOC is proposed to communicate with certain agents in an observable filed. Only nearby agents are able to participate in a communication group, which is determined by a probabilistic gate mechanism. Within a communication group, a bi-LSTM is used to automatically combine messages sent from each agent and to send back to each member.
  + <https://arxiv.org/abs/1805.07733>
* IC3Net [24], extended from CommNet, also uses a gate mechanism, while deterministically decides to send a message to either all agents or to no agent at all. In addition, IC3Net employs individualized rewards for each agent rather than a globally shared reward as used in CommNet, thus showing more diverse behaviours in competitive/mixed environment.
* ETCNet [27] also uses a gate for each agent to decide whether to broadcast their messages. However, the overall probability of sending messages is regularized by a penalty term during optimization, in order to reduce communication overhead.
  + <https://arxiv.org/abs/2010.04978>
* I2C [28] measures casual effect of considering other agents’ actions on each agent’s own strategy. Then each agent decides whether to communicate with others in a peer-to-peer way.
  + <https://arxiv.org/abs/2006.06455>

Although a gate unit provides flexible decisions for communication, we could prioritize the chances of communication or explicitly establish a communication graph in a global way.

* SchedNet [25] learns to choose a certain number of agents to broadcast their messages.
* GA-Comm [22], MAGIC [13] and FlowComm [14] learn a shared graph for agents to decide whether and with whom to communicate.
  + GA-Comm
    - <https://arxiv.org/abs/1911.10715>
  + MAGIC
    - <https://www.ifaamas.org/Proceedings/aamas2021/pdfs/p964.pdf>
  + FlowComm
    - <https://www.ifaamas.org/Proceedings/aamas2021/pdfs/p456.pdf>
* GA-Comm learns an undirected communication graph by using attention mechanism to decide which pair of agents can communicate with each other.
* In contrast, MAGIC and FlowComm generate more fine-grained control by building directed graph among agents. Then connected agents can communicate with others unilaterally or bilaterally.

Some works use predefined relations among agents to decide when and with whom to communicate, while learning the content of messages.

* Agent-Entity Graph [29] utilizes a pretrained graph to maintain relations between agents. Then connected agents will communicate their individual encoding of observations and observable entities in the environment.
  + <https://arxiv.org/abs/1906.01202>

Agents could also explicitly send signatures with messages to inform other agents how to address the importance of messages.

* TarMAC [20] and IMMAC [35] use a broadcast way for each agent to send messages with signatures. Agents who receive messages assign weights to each message by considering associated signature. Different from IMMAC, TarMAC employs an attention mechanism to produce weights while IMMAC uses softmax.
* The attention mechanism is also exploited in GAComm [22] due to the flexibility and strength. GA-Comm learns two attention layers, one for deciding whether to communicate with others, and another for determining the relative importance between agents, together with a GNN network to aggregate messages.
* Nevertheless, the importance of messages can be learned via neural network implicitly. BiCNet [36] proposes to connect each agent’s policy and value function by bi-LSTM layers. Thus agents are able to capture others’ memory states with long term dependency and exchange messages accordingly.
* MD-MADDPG [37] allows agents to maintain a shared memory, which serves as the context of their world. Then agents learn to sequentially read and write the memory as in LSTM.

Limited bandwidth

* Gated-ACML [26] proposes to actively prune messages in two steps. The first step is similar to ATOC and IC3Net, which learns a gate mechanism to choose whether to send messages or not. In the second step, however, Gated-ACML assumes a centralized message coordinator that coordinates messages and sends back to each agent. Communication can be reduced since in theory each agent only needs to communicate with one another, that is the coordinator.
* Inspired from information theory [41, 42], IMAC [21] and ETCNet [27] formalise limited bandwidth as optimization constraints. IMAC claims that limited bandwidth requires agents to send low-entropy messages and propose to clip messages’ variance. ETCNet deduces an upper bound of the probability that agents are allowed to send messages at each step, and then optimizes under the constraint of limited bandwidth.
* Variable-length Coding [43] also considers the case of limited bandwidth, while agents regulate the number of bits they send at a given time step.

Deciding when to communicate

* Individualized Controlled Continuous Communication Model (IC3Net)[21]
  + Extended from CommNet
  + Controls communication with gating mechanism to decide when to communicate and uses individualized rewards for each agent to gain better performance and scalability
  + Applied to cooperative, semi-cooperative and competitive settings
* <https://arxiv.org/pdf/1902.01554.pdf>
  + SchedNet
  + Limited bandwidth
  + the agents share the communication medium so that only a restricted number of agents are able to simultaneously use the medium
    - to simulate state-of-the-art wireless network architectures
  + Learns to decide which agents should be entitled to  
    broadcasting their (encoded) messages, by learning the importance of each agent’s  
    partially observed information.